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Ground Water Contamination In The Northeast States

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GROUND WATER CONTAMINATION

IN THE NORTHEAST STATES

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ABSTRACT

An evaluation of principal sources of ground-water contamination has been carried out in 11 northeast states, including all of New England, New York, New Jersey, Pennsylvania, Maryland, and Delaware. The findings of this study have been used to determine priorities for research into ways to reduce the number of sources of contamination and to point out deficiencies in present control methods for protecting against further degradation of ground-water quality.

Ground-water quality in the region is generally good to excellent, except for naturally occurring saline waters in some coastal and inland aquifers. Principal sources of ground-water quality degradation caused by man's activities that are common to most parts of the region are septic tanks and cesspools, buried tanks and pipelines including sanitary and storm sewers, the application and storage of highway de-icing salts, municipal and industrial landfills of solid waste, unlined surface impoundments, spills, and the uncontrolled discharge of pollutants on the land surface. In New York and Pennsylvania, mining and petroleum exploration and development have caused many instances of ground-water contamination, but the extent of the problem has not been defined. Salt-water intrusion in coastal areas has been adequately controlled, but little is known of the potential threat to fresh-water aquifers from the encroachment of saline water that occurs in inland formations underlying the western portions of the region.

The findings of the investigation indicate that the hundreds of cases of ground-water contamination recorded to date and referenced in this report represent only a very small percentage of those that actually exist. Furthermore, the technology to adequately solve problems of ground-water contamination has not been developed and made available to regulatory agencies. Basic research is needed on how to improve methods to inventory and correct problems of ground-water contamination and how to prevent future problems through better management and control of activities that can affect ground-water quality.

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SECTION I

CONCLUSIONS

1. Total use of ground water in the 11-state region in 1970 was approximately 3.4 billion gallons per day, with ground water supplying 20 percent of community, 93 percent of rural, 14 percent of industrial, and 47 percent of irrigation requirements.

2. Ground water can be developed almost anywhere in the region. Sand and gravel, and some sedimentary rocks are the principal aquifers.

3. The natural quality of ground water is generally good to excellent, except for the occurrence of saline waters in some coastal and inland aquifers.

4. The most common natural water-quality problems in fresh-water aquifers are high iron content, often associated with a high concentration of manganese; low pH; and high hardness.

5. The most significant source of ground-water contamination is the discharge of sewage from septic tanks and cesspools, serving an estimated 12 million people in the region. Inadequate experience and lack of sound scientific planning on the use of on-site disposal systems have led to some regional and many local problems.

6. Buried storage tanks and pipelines, including sanitary and storm sewers, are significant sources of ground-water contamination where pollutants have leaked directly into shallow aquifers. The most troublesome pollutants from this source are hydrocarbons and industrial wastes containing toxic substances.

7. The storage and spreading of several million tons of highway deicing salts each year in the northeast have led to numerous problems of ground-water quality degradation. Some domestic and public supply wells have been abandoned, and records of water quality from many others have shown a gradual but significant trend of increasing concentrations of chloride, sodium, and other ions.

8. The thousands of acres of landfills containing municipal and industrial solid wastes are an almost universal source of ground-water contamination in the region.

9. Lagoons, pits, and basins, which are a common means for treating, handling, and storing liquids and sludges, are leaking many million gallons per year of potentially hazardous substances to ground water.

10. Spills and uncontrolled surface discharges of pollutants have resulted in some severe problems of ground-water quality degradation. Various types of hydrocarbons and industrial process and waste liquids are the principal pollutants.

11. The extent of ground-water contamination from mining activities, principally involving coal in western Pennsylvania and Maryland, has not been well defined. However, available data indicate that mine drainage, leachate from waste rockpiles, and leakage from tailing ponds may be significant sources of ground-water contamination in areas containing numerous abandoned and active workings.

12. The high yield of salt water from tens of thousands of marginally producing oil and gas wells in western Pennsylvania and western New York represents the principal threat to fresh-water aquifers from petroleum exploration and development. Little information has been collected on the actual extent and character of ground-water quality problems related to activities involved in petroleum exploration and development.

13. Salt-water intrusion in coastal areas of the region was widely recognized about forty years ago as a major threat to fresh-water aquifers. Consequently, the problem has been well-defined and adequately controlled.

14. The movement of natural saline waters into fresh-water aquifers in the inland areas of the western portion of the region, as influenced by pumping, has not been studied in detail except in a few locations and represents a continuing problem.

15. In spite of the large number of municipal and industrial high capacity wells that are pumping water infiltrated from surface streams which are considered polluted, few cases of severe ground-water contamination have been recorded. The major problem commonly reported is a build-up of iron and manganese concentrations requiring ultimate treatment of the well water.

16. The practice of disposing of industrial and sewage wastes through deep injection wells in saline-water

aquifers is almost non-existent in the region and represents an unimportant source of ground-water contamination.

17. The disposal of storm waters and, in a few cases, industrial and sewage wastes through recharge basins and wells into fresh-water aquifers is common in some parts of the region. Although few instances of ground-water contamination have been reported, long-term effects on ground-water quality have not been studied in enough detail to determine the importance of this potential source of contamination.

18. The spraying of liquid wastes onto land as a means of disposal and treatment has been carried out on a limited basis in each of the 11 states of the study region. However, because of a general lack of monitoring and/or inadequate evaluation of data collected from monitoring wells, little is known at present with regard to the feasibility of protecting ground-water quality when municipal and various types of industrial wastes are applied to the land surface.

19. Abandoned and poorly constructed water wells can serve as a means for transmission of pollutants from one aquifer to another, or from land surface to an aquifer. This problem is most severe in areas underlain by formations containing naturally occurring saline water, in highly industrialized areas where spills and uncontrolled surface discharges of pollutants are common, and in rural areas where there is a high incidence of shallow, dug wells.

20. A number of cases of ground-water contamination related to agricultural activities have been reported in the region. The principal pollutants are nitrates from fertilizers and animal wastes, and a variety of substances from pesticides. The potential for ground-water contamination in suburban areas, from the heavy use of fertilizers and pesticides by individual home owners, may be considerably greater than in farmed areas.

21. Only a very small percentage of the instances of ground-water contamination from all sources that probably exist in the region has been discovered to date. Of the more than one thousand cases inventoried in this investigation, almost all were reported only after a water-supply well or spring had been noticeably affected or the pollutant was being discharged to the surface.

22. The problem of ground-water contamination has not been corrected from either the standpoint of removing the source of contamination or significantly improving the quality of the affected ground-water supply in most of the cases inventoried.

23. The principal reasons for the lack of success in dealing with existing ground-water contamination problems in the northeast are deficiencies in the technology presently available to satisfy economic, social, and political restraints; inadequate budgeting and staffing together with the diverse interests of regulatory agencies; and the general lack of understanding in the region as to how the various activities of man can degrade ground-water quality.

SECTION II

RECOMMENDATIONS

1. A basic need in the region is a reevaluation of priorities governing present budgetary allocations to regulatory agencies, with a greater appreciation of the increasingly important role that ground water plays in meeting essential needs for high quality water.

2. Chemical analyses of ground-water quality must be expanded to cover a wider variety of inorganic and organic compounds on a more routine basis.

3. More effective methods must be developed for conducting inventories of potential sources of ground-water contamination on a regional basis.

4. The monitoring of suspected sources of ground-water contamination must be expanded, especially those that might be introducing pollutants into the ground that could be harmful to health, and those that are situated in areas where existing wells may be threatened.

5. Additional research is needed on the development and application of more scientific and dependable ways to delineate the areal extent and characteristics of pollutants contained in aquifers and their fate over the long term.

6. Basic research is needed on how to economically remove or control the movement of various types of pollutants affecting ground-water quality.

7. The various options presently available to regulatory agencies for the future protection of ground-water quality must be reevaluated. Alternatives should be made available through research and analysis that are suitable on the one hand to meet various geologic and hydrologic conditions and on the other hand to overcome economic, social, and political restraints.

8. Additional research is needed on how to reduce the susceptibility of aquifers to water-quality degradation through the development and application of improved methods for analyzing the many factors involved in the siting, design, and operation of various activities that could become sources of ground-water contamination.

9. Increased regulation and control is needed to reduce, as much as possible, new instances of ground-water contamination. This includes calling for procedures to contain toxic pollutants on the land surface, requiring detailed information on which environmental decisions can be based, and enforcing design and operational procedures that are productive.

SECTION III

INTRODUCTION

Three basic factors determine the feasibility of developing ground water in the northeastern United States: (1) availability, (2) water quality, and (3) economics. This report discusses the role that water-quality problems play in limiting ground-water use in the region. It is based on an investigation supported by the U. S. Environmental Protection Agency and covers 11 states including Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, Maine, New York, New Jersey, Pennsylvania, Delaware, and Maryland.

Similar reports have been published for four southwestern states and five south-central states. [1,2] An investigation of ground-water contamination is underway in six northwestern states. [3] The rest of the nation will be covered in subsequent reports.

Natural ground-water quality together with the geologic setting and occurrence of principal aquifers are described in the next sections of this report on a state-by-state basis. This is followed by a discussion of the principal sources of ground-water contamination in the region. The final section recommends research and other needs required to combat the problems of ground-water pollution and contamination, based on the findings of the investigation.

Information on natural water quality and aquifer systems was obtained from a careful review of literature on the region. Published data were also surveyed in an effort to obtain data on specific cases of ground-water contamination and many valuable references were used in the following discussion. However, few of the known instances of contamination have been reported in the literature. In order to gain a true perspective on the status of ground-water contamination it was necessary to contact, mostly by personal visit, several hundred public officials, consultants, scientists, well drilling contractors, representatives of industry, and others involved in water supplies so that their files and individual experience could be applied to the study.

Throughout the report, the terms "pollution" and "contamination" are synonymous and mean the degradation of natural water quality, as a result of man's activities, to the extent that its usefulness is impaired. There is no implication of any specific limits (such as those in the U. S. Public

Health Service drinking water standards), since the degree of permissible pollution depends upon the intended end use, or uses, of the water. Increases in concentration of one or more constituents as the natural result of movement of ground water through an aquifer are referred to as "mineralization".

It is recognized that these definitions are perhaps simplistic, but at least they avoid the logical impasses to which some other definitions lead. Also, they are readily understandable. "Pollution" has long implied the activity of man, and hence the term "natural pollution" is confusing as well as unnecessary. [4]

USE OF GROUND WATER

In 1970, the total fresh ground-water withdrawal in the nation was 68 billion gallons per day or 21 percent of all fresh water withdrawn. [5] For the project area, 18 percent of total water used was from ground-water sources. Water use in the 11 states of the region is shown on Table 1; water for hydroelectric and thermoelectric power is excluded in all computations. Surface and ground-water withdrawals for public and rural supply, self-supplied industry, and irrigation are given as of 1970. Ground water provided 20 percent of public, 93 percent of rural, and 14 percent of industrial supplies. Forty-seven percent of the water required for irrigation was also ground water. States in which ground water comprises approximately 25 percent or more of the total water needs are Connecticut, Massachusetts, New Jersey, Rhode Island, and Vermont. Ground water in these states is used mostly for public supply or industry, which is true for the region as a whole. Vermont is the exception because of its largely rural population; in this case, ground water is used mostly for on-site, domestic supply. New Jersey has the largest total ground-water withdrawal (1,027 mgd) even though it ranks third in population (7,200,000). The state with the smallest amount of ground-water diversion is Maine (35 mgd), even though it has the seventh largest population (990,000).

FUTURE USE

Future need for water should increase considerably over existing requirements and consumptive uses. The U. S. Water Resources Council in 1968 published a comprehensive report on the nation's water resources. [6] A portion of the report deals with water needs for the future on a regional basis. Table 2 is a compilation of the data for the North Atlantic

Table 1. ESTIMATED USE OF WATER IN THE NORTHEAST UNITED STATES IN 1970.
(million gallons per day) [5)]

State	Public supply	Rural supply a)	Industrial b) Fresh	Industrial b) Saline	Irrigation	Total
CONNECTICUT						
Ground water	86	40	20	1	0.5	147.5
Surface water	270	1.2	55	130	5.4	461.6
Total:	356	41.2	75	131	5.9	609.1
Percent of total that is ground water	24	97	27	1	8	24
DELAWARE						
Ground water	30	13	22	0	2.2	67.2
Surface water	46	0.1	64	300	0.5	410.6
Total:	76	13.1	86	300	2.7	477.8
Percent of total that is ground water	40	99	26	0	81	14
MAINE						
Ground water	20	12	3	0	0.2	35.2
Surface water	89	2.8	400	24	8.7	524.5
Total:	109	14.8	403	24	8.9	559.7
Percent of total that is ground water	18	81	1	0	2	6

a) Domestic and livestock supplies.
b) Water for hydroelectric and thermoelectric power excluded.

Table 1 (continued). ESTIMATED USE OF WATER IN THE NORTHEAST UNITED STATES IN 1970.
(million gallons per day) [5)]

State	Public supply	Rural supply [a)]	Industrial [b)] Fresh	Industrial [b)] Saline	Irrigation	Total
MARYLAND						
Ground water	42	57	43	0	2.1	144.1
Surface water	380	0.5	450	820	4.3	1,654.8
Total:	422	57.5	493	820	6.4	1,798.9
Percent of total that is ground water	10	99	9	0	33	8
MASSACHUSETTS						
Ground water	170	30	140	0	18	358
Surface water	590	0.8	390	160	40	1,180.8
Total:	760	30.8	530	160	58	1,538.8
Percent of total that is ground water	22	97	26	0	31	23
NEW HAMPSHIRE						
Ground water	32	12	12	0	0	56
Surface water	38	1	180	0	2.8	221.8
Total:	70	13	192	0	2.8	277.8
Percent of total that is ground water	46	92	6	0	0	20

Table 1 (continued). ESTIMATED USE OF WATER IN THE NORTHEAST UNITED STATES IN 1970.
(million gallons per day) 5)

State	Public supply	Rural supply a)	Industrial b) Fresh	Industrial b) Saline	Irrigation	Total
NEW JERSEY						
Ground water	340	81	550	0	56	1,027
Surface water	560	0.9	450	0	20	1,030.9
Total:	900	81.9	1,000	0	76	2,057.9
Percent of total that is ground water	38	99	55	0	74	50
NEW YORK						
Ground water	460	140	140	1.7	14	755.7
Surface water	2,200	13	1,300	64	13	3,590
Total:	2,660	153	1,440	65.7	27	4,345.7
Percent of total that is ground water	17	92	10	3	52	17
PENNSYLVANIA						
Ground water	250	120	400	0	0.8	770.8
Surface water	1,500	14	5,000	50	9.4	6,573.4
Total:	1,750	134	5,400	50	10.2	7,344.2
Percent of total that is ground water	14	90	7	0	8	10

Table 1 (continued). ESTIMATED USE OF WATER IN THE NORTHEAST UNITED STATES IN 1970.
(million gallons per day) [5]

State	Public supply	Rural supply [a]	Industrial [b] Fresh	Industrial [b] Saline	Irrigation	Total
RHODE ISLAND						
Ground water	18	4.7	15	0.4	0.4	38.5
Surface water	85	0.1	23	0	4.1	112.2
Total:	103	4.8	38	0.4	4.5	150.7
Percent of total that is ground water	18	98	39	100	9	26
VERMONT						
Ground water	14	16	12	0	0	42
Surface water	29	3.1	34	0	0.1	66.2
Total	43	19.1	46	0	0.1	108.2
Percent of total that is ground water	33	84	26	0	0	39
GRAND TOTAL						
Ground water	1,462	525.7	1,357	3.1	94.2	3,442
Surface water	5,787	37.5	8,346	1,548	108.3	15,826.8
Total:	7,249	563.2	9,703	1,551.1	202.5	19,268.8
Percent of total that is ground water	20	93	14	0.002	47	18

Table 2. ESTIMATED AND PROJECTED USE AND REQUIREMENTS OF WATER FOR THE NORTH ATLANTIC REGION, UNITED STATES. (million gallons per day) [6]

	Use in 1965	Withdrawals Projected Requirements 1980	2000	2020
Total estimated water use and projected requirements	37,467	54,920	113,860	236,290
Municipal water requirements	5,446	7,100	10,000	14,200
Rural domestic water requirements	390	400	400	400

	Use in 1965	Consumptive Use Projected Requirements 1980	2000	2020
Total estimated water use and projected requirements	2,023	2,870	4,960	8,490
Municipal water requirements	905	1,210	1,750	2,550
Rural domestic water requirements	186	200	200	200

Region, which includes a major portion of the 11-state study area. According to this projection, water requirements during the period 1980 to 2020 will increase more than fourfold. Self-supplied industrial water needs alone for the year 2020 have been estimated at almost 35 billion gallons per day in the North Atlantic Region. 7) The national average per-capita use also is anticipated to increase. Table 3 is projected per-capita use within the conterminous United States.

With the increased competition for water supplies, several interrelated factors become obvious. The demand for land for housing has significantly reduced the already limited sites suitable for surface-water impoundments. The present high cost of land will continue to have a profound influence on the present trend of municipalities and other large water users to give increased consideration to the development of supply wells, which take up comparatively little space, rather than surface-water supplies. As urban and industrial expansion takes place, there will be a greater need to transport water from areas of surplus to areas experiencing shortages. The high cost involved in piping large quantities of surface water should accelerate exploitation of local ground-water supplies. Also, by the year 2020, it is estimated that the population in the region will almost double to over 100 million. 7) With the rise in population will come a rise in water demand, satisfied to a significant degree by the development of additional ground-water sources.

Table 3. PROJECTED PER CAPITA WATER WITHDRAWALS FOR PUBLIC AND INDIVIDUAL WATER-SUPPLY SYSTEMS. (gallons per capita per day) [6]

Year	Public water-supply systems	Individual water-supply systems
1965	157	51
1980	163	58
2000	168	71
2020	170	83

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SECTION IV

DESCRIPTION OF PROJECT AREA

The project covers the 11 states of Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont, an area of over 180,000 square miles. Six percent of the total conterminous United States land surface is represented. Figure 1 shows the locations of the states in the study area. Typical of this region are hilly to mountainous areas, coastal plains, and some marshy lowlands, with most of the land in the first category. Altitude ranges from sea level along the Atlantic Coast to nearly 6,300 feet in the White Mountains of New Hampshire. Much of the region has been subjected to urban development but large sections are still rural with agricultural and forest lands.

PHYSIOGRAPHY

The project area exhibits a wide variety of physical features. These different land forms have a profound effect as to the use of the land, location of population centers, and occurrence of natural resources. In the southeastern portion, the land is characterized by broad areas of relatively minor relief, while to the west and north the land rises to hilly and rugged mountainous terrain.

The classification devised by Thomas divides the continental United States into ten ground-water regions. [1)] Based on this system, the study area includes portions of five of these regions (Figure 2):

1. Coastal Plain
2. Unglaciated Appalachians
3. Glaciated Appalachians
4. Glaciated Central Region
5. Unglaciated Central Region

The Coastal Plain is characterized by seaward-dipping unconsolidated strata, consisting of clay, marl, silt, sand and gravel, Cretaceous to Quaternary in age. The surface relief is very moderate with topographic highs rarely exceeding a few hundred feet above sea level. The sediments range in thickness from a thin veneer along the Fall Line, which is the western limit of this province, to as much as 10,000 feet along the eastern coast of Maryland.

The Coastal Plain contains prolific ground-water resources.

Figure 1. Locations of the states in the northeast study area

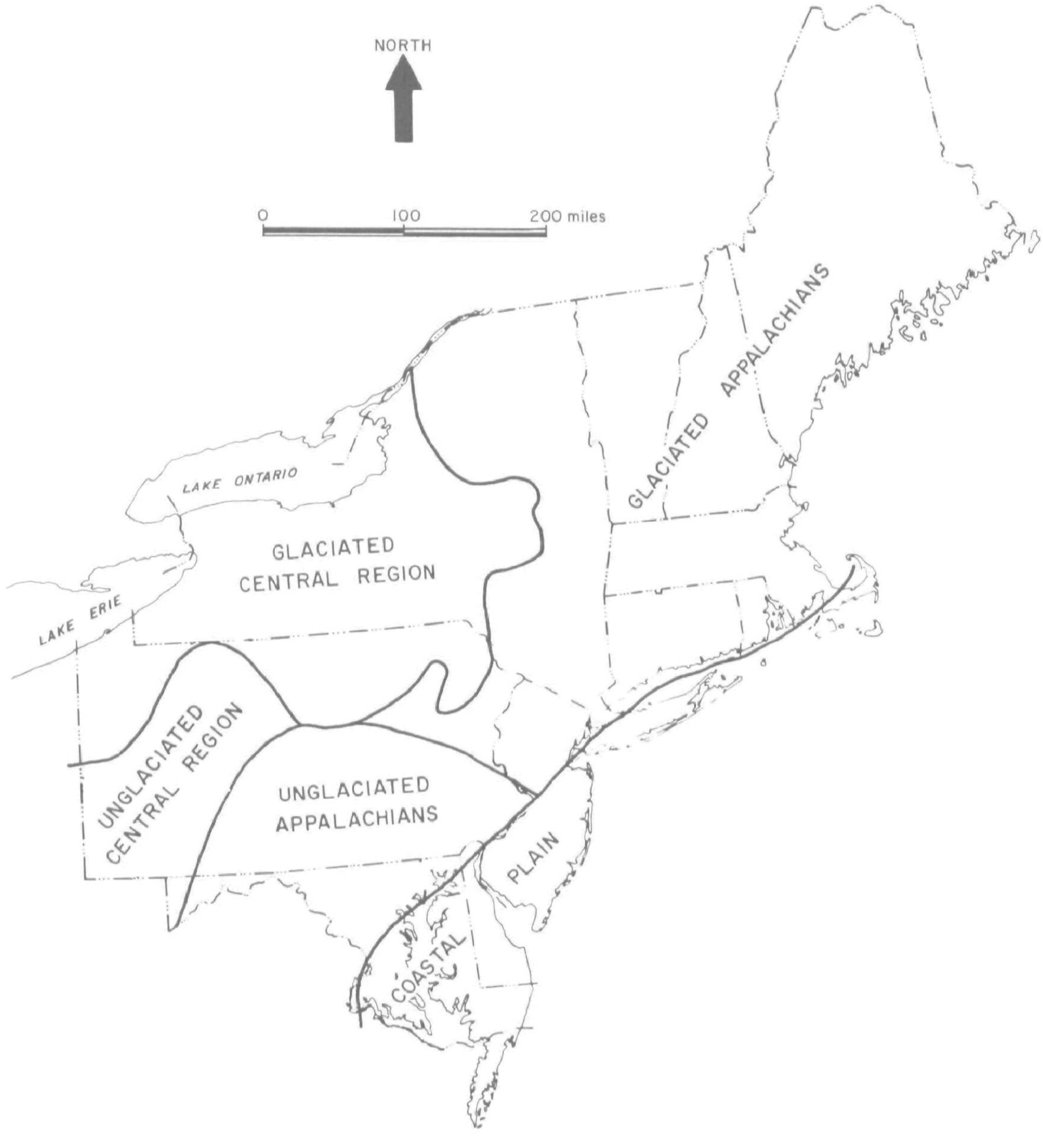

Figure 2. Ground-water regions in the northeast United States [1]

Because of the presence of thick and permeable sand and gravel zones and the great areal extent of individual aquifers, high capacity wells and major ground-water supplies have been developed throughout the province.

The Unglaciated Appalachians are characterized by folded consolidated rock units forming a ridge and valley topography. The upland relief is characteristically 1,000 to 3,000 feet above sea level. Aquifers include sand and gravel beds in alluvium associated with perennial streams, dense crystalline or sedimentary rocks, and some cavernous limestones.

The alluvial deposits, although of limited areal extent, offer the best potential for high-yielding wells, especially where infiltration from surface streams can increase recharge. The limestones can be excellent aquifers where solution cavities are encountered by a particular well. The dense igneous, metamorphic, and sedimentary formations are the poorest aquifers in the province but are important because they are so extensive. Typical well yields from these dense rocks range from only a few gpm (gallons per minute) to as much as 200 gpm.

The Glaciated Appalachians are characterized by hilly or mountainous terrain, with thin glacial drift on the uplands and thick outwash and lacustrine deposits in the valleys. Local relief can be between 1,000 and 3,000 feet, with several mountain crests above 5,000 feet in elevation, the highest being just under 6,300 feet. Bedrock is predominantly crystalline. However, two broad belts of Triassic sandstone and shale are important aquifers. One underlies a portion of northern New Jersey and the other occupies the central lowlands of Connecticut and Massachusetts.

The glacial deposits are by far the most important aquifer in the region. Although individual sand and gravel beds are limited in areal extent, they are sometimes thick and permeable enough to supply municipal or industrial water-supply systems that pump millions of gallons per day. The greatest ground-water potential occurs where recharge is supplemented by river infiltration.

The crystalline rocks have been developed over the entire region but have generally been used only for domestic or small commercial water supplies because of the characteristically low yields of individual wells. The Triassic sandstone and shale, especially in New Jersey, is a principal source of ground water for municipal and industrial purposes. Wells yielding from 100 to 500 gpm are common.

The Glaciated Central Region is characterized by glacial drift overlying crystalline and sedimentary rocks. The land is one of gentle slopes and only moderate relief, characteristically between 100 and 300 feet. The sedimentary formations are the most productive of the consolidated rocks. For the most part, the glacial deposits are thin or of low permeability and are primarily used for domestic supplies. Exceptions to this are those areas where thick beds of sand and gravel occur in existing stream courses or abandoned pre-glacial bedrock valleys.

The Unglaciated Central Region is found only in western Pennsylvania within the study area and is characterized by nearly horizontal sedimentary rocks of Mississippian, Pennsylvanian, and Permian age. Local relief is on the order of 300 to 500 feet. The principal aquifers consist of alternating strata of shale, siltstone, sandstone, and limestone. Well yields average about 50 to 75 gpm.

POPULATION

As of the 1970 Census, 53.5 million or 26.3 percent of the nation's 203.2 million people reside in the project area (Table 4). The population is heavily concentrated in the urban areas, particularly in the Boston to Washington, D. C. megalopolis. Population for the entire region increased by 11 percent between 1960 and 1970.

CLIMATE

The overall climate of the 11-state region is humid and is characterized by frequent weather changes. The dominant characteristics of the climate are provided by masses of cold, dry air from the northern interior of the continent and by masses of warm, humid air from the Gulf of Mexico. A secondary climatic influence is represented by masses of cool, damp air from the North Atlantic Ocean.

The climate is moderated by the ocean along the coast and the Great Lakes in the northwest. Interior land areas and particularly the mountainous regions exhibit more marked extremes in temperature and precipitation. The average annual temperature in the region varies from less than 38°F in northern Maine to more than 58°F in southern Maryland. [3]

Precipitation is distributed fairly evenly throughout the four seasons in most of the region. The average annual precipitation is shown on Figure 3. Annual snowfall averages 18 inches in Delaware to over 100 inches in parts of northern New York and New England.

Table 4. POPULATION OF ELEVEN NORTHEAST STATES.[2)]

State	1970 Population	Percent increase 1960 to 1970	Population distribution Percent urban	Percent rural
Connecticut	3,032,217	19.6	77.3	22.7
Delaware	548,104	22.8	72.2	27.8
Maine	993,663	2.5	50.7	49.3
Maryland	3,922,399	26.5	76.6	23.4
Massachusetts	5,689,170	10.5	84.6	15.4
New Hampshire	737,681	21.5	56.4	43.6
New Jersey	7,168,164	18.2	88.9	11.1
New York	18,241,266	8.7	85.5	14.5
Pennsylvania	11,793,909	4.2	71.5	28.5
Rhode Island	949,723	10.5	86.9	13.1
Vermont	444,732	14.1	32.1	67.9
Total:	53,521,028	11.0	81.5	18.5

Figure 3. Precipitation map of the northeast United States [5]

The average annual evaporation from open water surfaces varies from 20 to 38 inches (Figure 4), generally increasing from north to south. Most of the evaporation occurs from May to October.

GEOLOGY AND GROUND-WATER RESOURCES

Following is a discussion of the general geology in relation to the ground-water resources on a state-by-state basis. Where the water-bearing characteristics of the aquifers are known, they are included to allow a more complete picture of the system. Since it is beyond the scope of this study to present a detailed breakdown of the geology and aquifer properties, the statements are couched in general terms. Specific references are given in the event that additional information is desired.

Connecticut

The bedrock in Connecticut consists of three significant rock groups: pre-Triassic crystalline rocks, Triassic sedimentary rocks, and Paleozoic carbonate rocks. They can yield water, in at least limited quantities, to individual wells almost everywhere. Unconsolidated deposits, mainly of glacial origin, can be found mantling the rock throughout the state. However, these deposits of sand, gravel, silt, and clay are only important from a water-supply point of view where a sufficient thickness is encountered, usually in the valleys of the principal drainage features and the coastal lowlands. Figures 5 and 6 are generalized geologic maps showing, respectively, the major bedrock units and the locations of the major coarse-grained, water-laid deposits.

Crystalline Rocks -

Crystalline rocks are the most areally extensive type found in the state. They are of pre-Triassic age and consist primarily of granites, gneisses, and schists. These rocks are the principal sources of well-water supplies in the upland regions and are primarily tapped by domestic, light industrial, and small public water-supply system wells.

In spite of their diverse origin and appearance, all of the crystalline rocks of Connecticut have similar water-bearing properties in that they generally have a limited capacity to store and transmit water. However, they represent an important source of water supply. Approximately 15 percent of the total population is dependent upon individual domestic wells, the vast majority of which tap the crystalline-rock aquifer. An analysis of records for more than 100 such

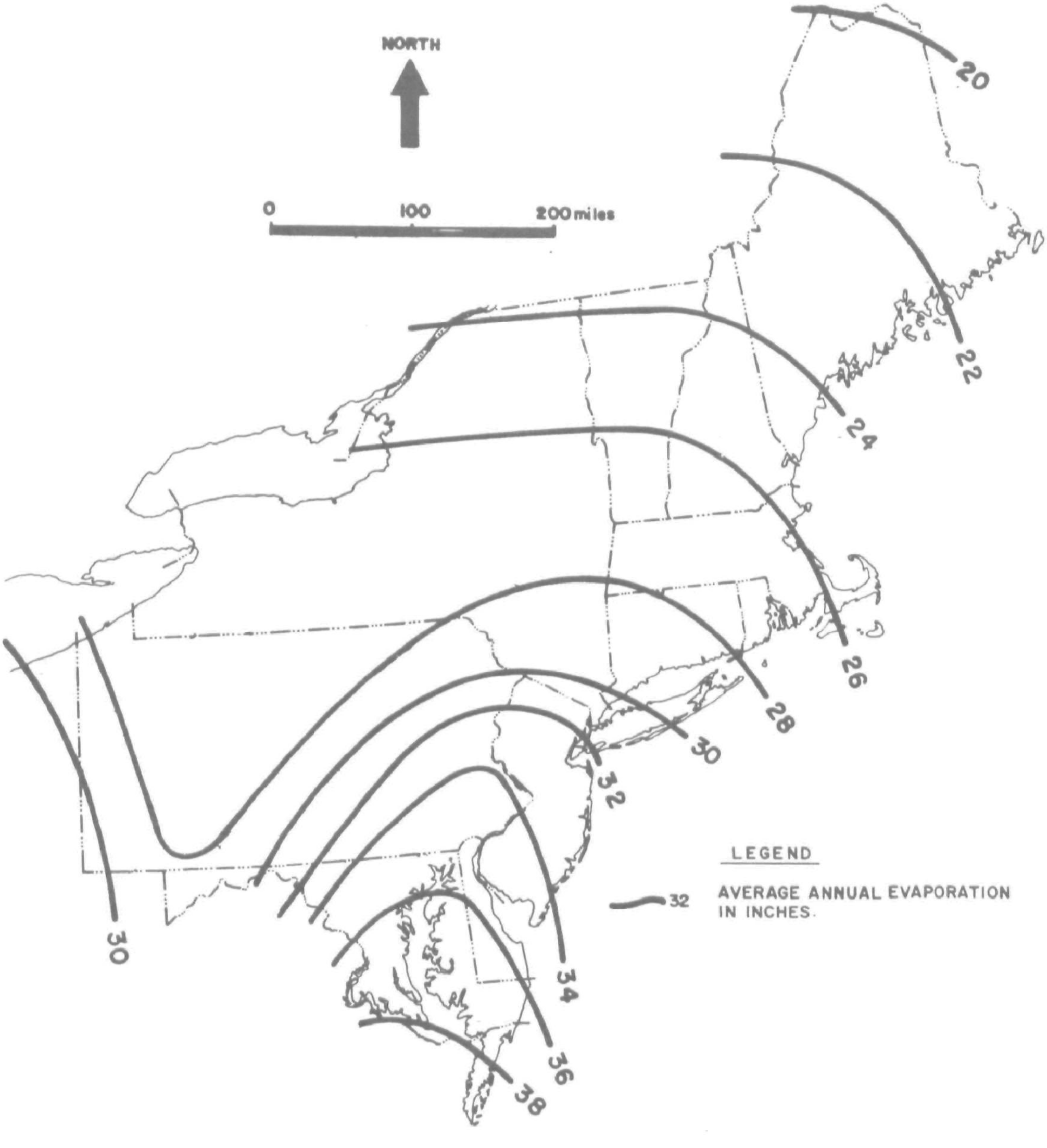

Figure 4. Average annual evaporation from open water surfaces [5)]

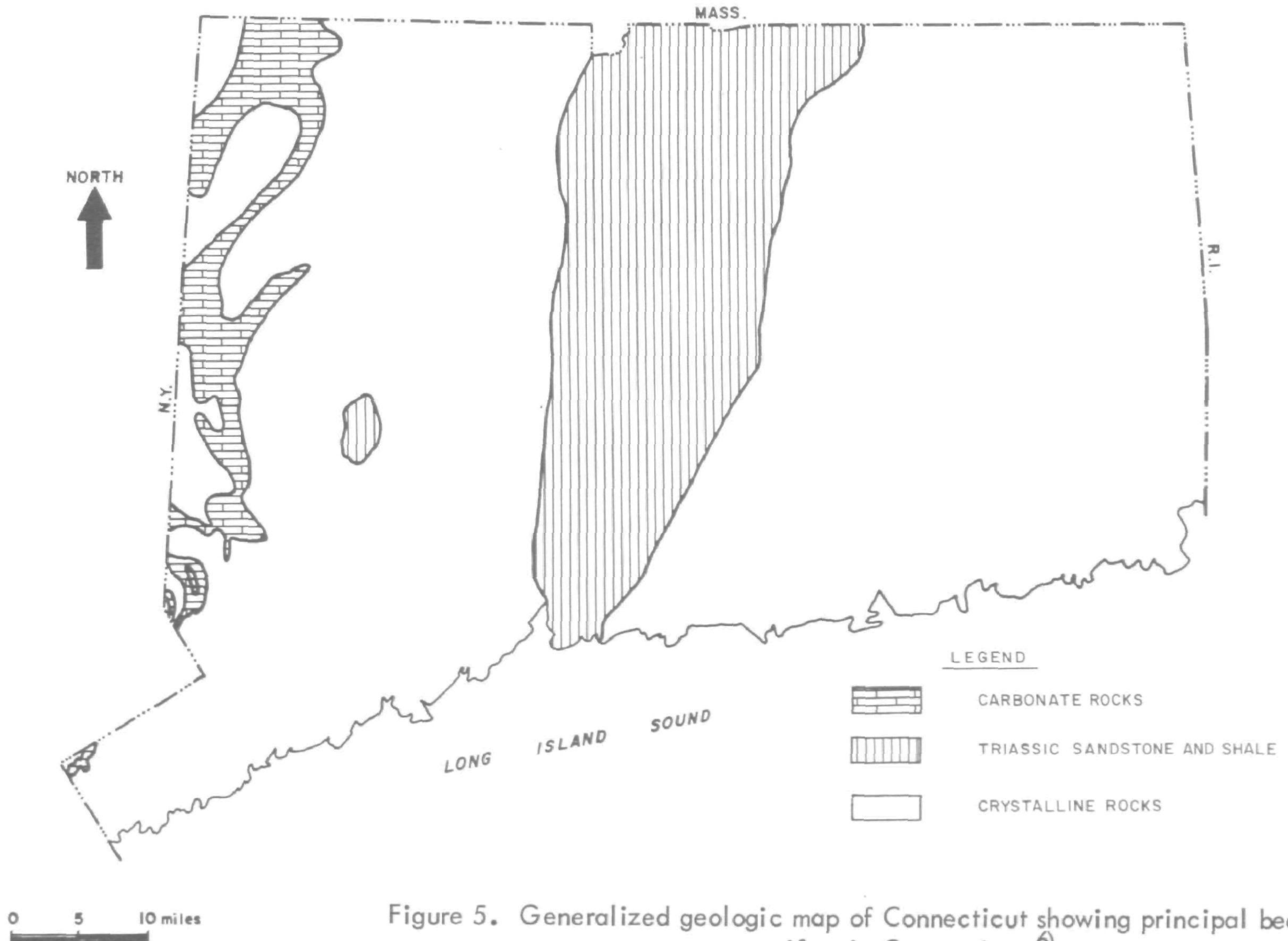

Figure 5. Generalized geologic map of Connecticut showing principal bedrock aquifers in Connecticut [6]

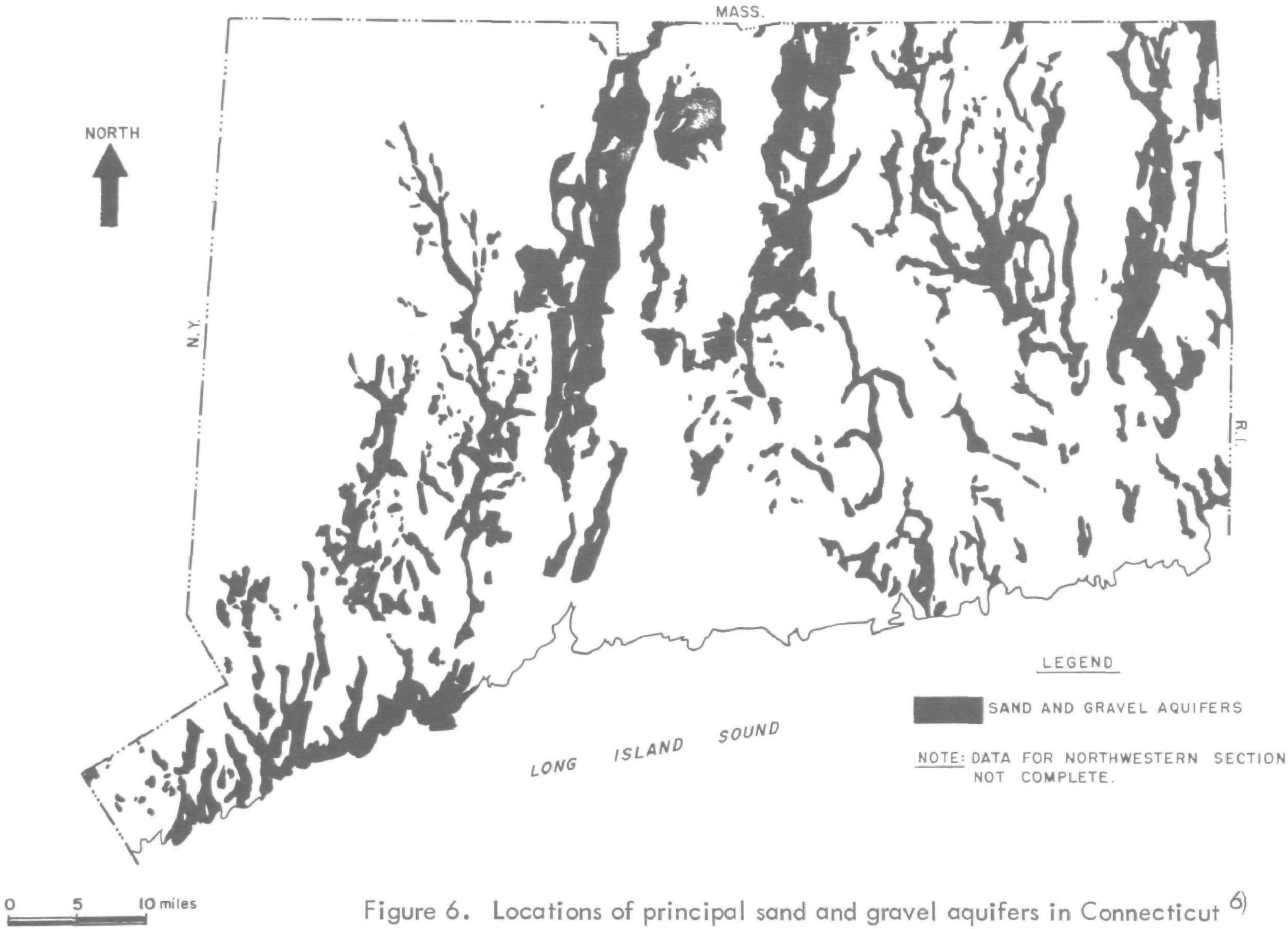

Figure 6. Locations of principal sand and gravel aquifers in Connecticut [6)]

wells reveals that the range in yield is from less than one to more than 100 gpm, with an average of five gpm. 7)

Sedimentary Rocks -

The second most extensive rock unit in Connecticut consists of siltstones, shales, and conglomerates of Triassic age, with the infrequent occurrence of diabase intrusives. Except for the intrusives, the rocks were deposited originally as unconsolidated continental sediments, and consequently the grain size varies greatly both horizontally and vertically from bed to bed. This variation in rock type has an effect on the availability of ground water in joints and fractures, along bedding planes, and in intergranular pore spaces. Beds of sandstone are generally more permeable than beds of shale because some water in the former is contained between individual sand grains where the cementing material has been dissolved or was never formed. Water in the shale is contained almost entirely in fractures, many of which are along bedding planes.

There has also been some faulting of the sedimentary rocks. In a few places, this has created large fractures which, upon being penetrated by a well, will yield a considerable quantity of water. Several wells drilled into sedimentary rock penetrate interbedded basalt flows as much as 50 or more feet thick. These basalts are poor aquifers, but deepening of some of the wells into underlying sedimentary rocks has improved yields substantially.

The water-bearing zones in the sedimentary rocks normally extend to depths greater than several hundred feet, and evidence obtained from the drilling of some wells shows a definite increase in yield as the bore hole is deepened to as much as 400 feet. An analysis of records of 688 wells tapping sedimentary rocks shows a range in yield from about one to as much as 600 gpm. 8) The average yield of the inventoried wells is 54 gpm. However, it should be noted that many of these wells are used only for domestic purposes, and the reported yield may simply reflect the installed pump capacity rather than the ability of the sedimentary rocks to furnish water.

In summary, the sandstones and shales of Triassic age are a more dependable source of water than the crystalline-rock aquifers in Connecticut. In many places, the sedimentary formations yield enough water to wells to satisfy small municipal, commercial, and industrial demands.

Carbonate Rocks -

Found only in the western portion of the state, the carbonate rocks consist of limestones that have been metamorphosed to marble. Generally, these are less resistant to weathering and erosion than the adjacent crystalline rocks and thus occupy the lowlands.

The carbonate rocks have virtually no primary porosity, and the saturated zones contain water in fractures and, to a lesser degree, in solution channels. A study of well yields indicates that the carbonate rocks have a somewhat higher yield than the crystalline rocks. The median yield of wells in crystalline rocks in the western portion of the state is about seven gpm, whereas the median in the carbonates is about 12 gpm.[9]

Unconsolidated Deposits -

The most prolific aquifers in Connecticut, from the standpoint of yields of individual wells and well fields, are the localized beds of unconsolidated sand and gravel laid down in bedrock valleys during the glacial epoch. In addition, some layers of sand and gravel of relatively recent age have been deposited by existing streams. Where beds of sand and gravel are well-sorted and relatively free of fine silt and clay, they tend to be very permeable.

Data on test borings and wells show that the thickness of unconsolidated materials throughout the state varies from a few feet to more than 200 feet in areas associated with many of the major river valleys, such as the Connecticut, Quinnipiac, Quinebaug, and Housatonic. Although some of the sand and gravel beds are very limited in areal extent, others cover as much as several square miles. Where thick permeable beds of sand and gravel are present below the water table and are areally extensive, yields in excess of 100 gpm can be developed from an individual well, and some wells can produce many hundreds of gpm.

In the case where the sand and gravel beds are in direct hydraulic connection with a surface-water body, a well yield is not limited by natural recharge from precipitation but is dependent upon the ability of water to infiltrate from the nearby stream or river. Individual wells finished in highly permeable unconsolidated deposits adjacent to large rivers in Connecticut are commonly capable of producing a sustained yield of more than one mgd (million gallons per day), and a number of well fields along the Housatonic, Connecticut, Hammonassett, and Quinebaug Rivers have a rated capacity in excess of five mgd. [7 through 11]

The other type of unconsolidated aquifer, used primarily in rural areas, is till. It consists of poorly sorted rock material: silt, sand, boulders, and clay. Although till deposits blanket most of the state, they are generally thin and of low permeability. Development is usually by large-diameter, shallow dug wells capable of producing a maximum of a few gpm.

The potential for development of additional high-capacity well fields in Connecticut is extremely good, especially in sand and gravel beds associated with the major rivers. Regional investigations carried out by the U. S. Geological Survey indicate numerous areas where untapped reserves of ground water exceed five to 10 mgd. For example, in the Quinebaug River basin, covering an area of 425 square miles, the estimate of ground water in sand and gravel aquifers available for development is 315 mgd. [11] In the Housatonic River basin, covering an area of 678 square miles, the estimate is about 660 mgd. [9]

Delaware

There are two basic rock types in Delaware; the crystalline rocks found in the Piedmont Province, and the unconsolidated sediments of the Coastal Plain. The crystallines in the northern part of the state consist of gneiss, marble, granodiorite, gabbro and serpentine, and comprise about six percent of the total land area. The unconsolidated deposits of the Coastal Plain consist of Cretaceous, Tertiary and Quaternary age sediments, consisting largely of sand and clay beds of marine and non-marine origin. They form a wedge-shaped mass, dipping to the southeast where they attain a thickness of over 8,000 feet. Figure 7 is a generalized geologic map of Delaware.

Crystalline Rocks -

Gneiss and gabbro comprise the bulk of the crystalline rocks found in the Piedmont of Delaware. Small patches of marble, serpentine and granodiorite are present, and narrow pegmatite dikes can be found throughout much of the province. The rocks are mantled by clays and sands which are a result of in-situ weathering. Alluvial materials are present in the lower sections of the river valleys.

Both the fresh rock and the weathered zone store considerable quantities of water. However, yields of individual wells are generally low in sections of the gabbro, which is

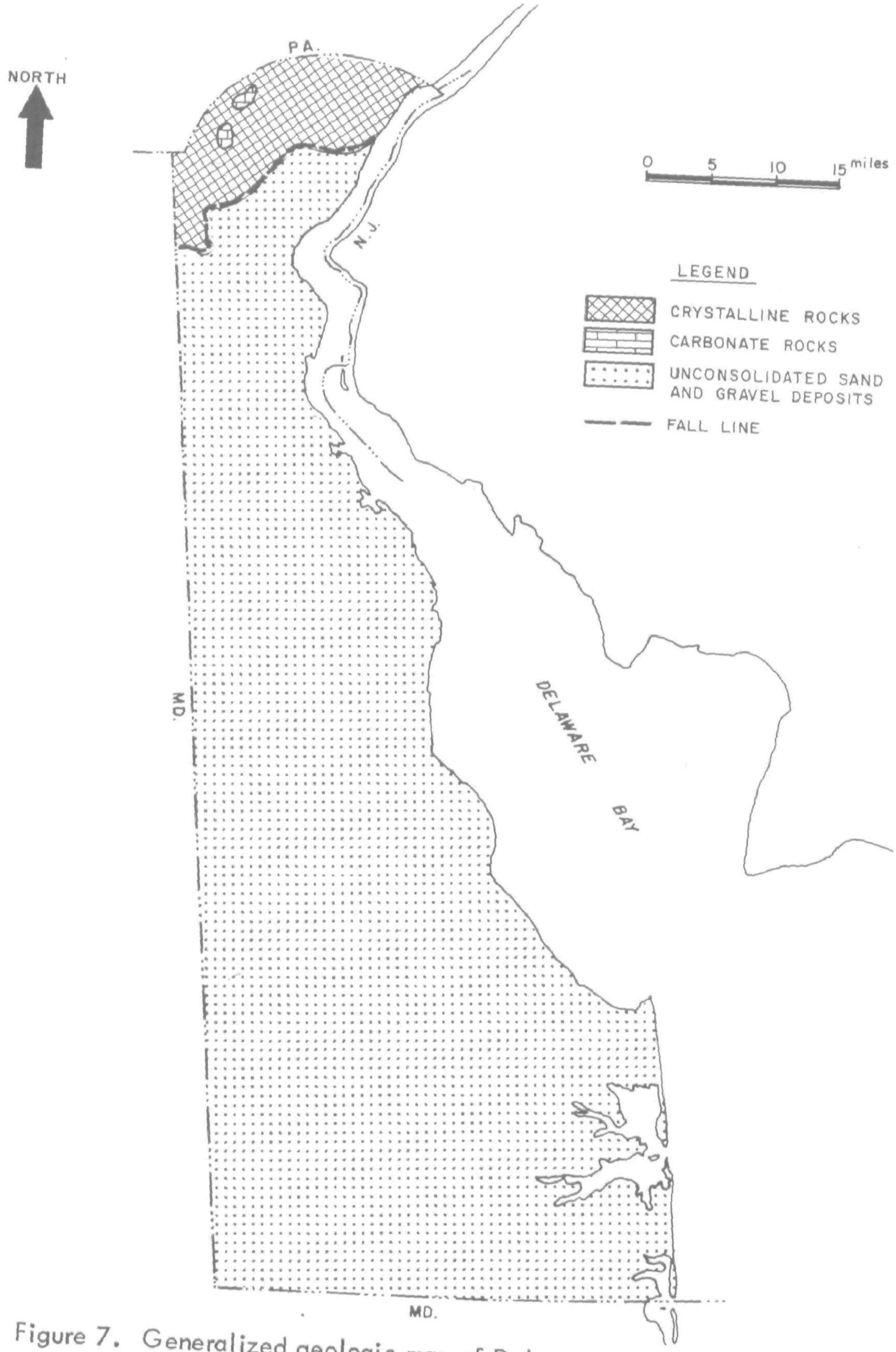

Figure 7. Generalized geologic map of Delaware showing principal aquifers [12, 13]

extremely tight with few saturated fractures. The marble generally provides higher yields than the other crystalline rocks.

The weathered zone is extremely variable in thickness within relatively short distances but is known to be greater than 85 feet thick in places.[12)] It is primarily tapped by dug wells for domestic supplies. The material is clayey in nature, although thin limited sand zones are occasionally present. Reports indicate that the main water-contributing zone occurs at the contact with the unweathered rock. Well yields average a few gallons per minute.

Unconsolidated Deposits -

The unconsolidated deposits of the Coastal Plain cover a major portion of the land area in the state. Table 5 lists the stratigraphic units, their generalized lithologic character, and their estimated average withdrawals during 1970 in Delaware. The hydraulic characteristics vary among the aquifers and from place to place within the same aquifer.

Quaternary age aquifers consist primarily of sandy material. They are the most highly developed and areally extensive in the state. Yields of individual wells have been reported to be as high as 4,000 gpm.[14)]

Several different aquifers of Tertiary age are recognized in Delaware. Many contain residual salt water in their down-dip portions. The sediments are of marine origin and vary widely in composition, the basal and down-dip portions containing increasingly finer material. Well yields of more than 600 gpm have been reported.[14)]

Cretaceous age deposits overlie the basement crystalline rocks and consist of a complex series of both non-marine and marine sediments. The marine Cretaceous sediments are of limited extent, thickness, and use in Delaware, containing salt water in much of the down-dip portion. The non-marine deposits, which attain a thickness of more than 6,000 feet, constitute the bulk of the unconsolidated sediments. Yields of wells tapping the Cretaceous deposits range from about three to 300 gpm.[14)]

Maine

Maine is located entirely within the Glaciated Appalachians ground-water region. From a hydrogeologic standpoint, the state has two types of aquifers, consolidated rock, and unconsolidated glacial sand and gravel. The consolidated rock

Table 5. COASTAL PLAIN STRATIGRAPHIC UNITS AND ESTIMATED AVERAGE WITHDRAWALS DURING 1970 IN DELAWARE. [12,13,14]

System	Series	Stratigraphic units	Generalized lithologic character	Estimated average withdrawals during 1970 (mgd)
Quarternary	Holocene	--------	Fluvial sand and gravel sand	33.32
	Pleistocene	Columbia Group undivided	Littoral and shallow marine clay, silt and sand	
Tertiary	Pliocene	--------		14.10
	Miocene	Chesapeake Group undivided	Marine sediments; gray quartz sand, gray silt and clay, shells and fragments of shells and diatomaceous material are common	
	Oligocene	SECTION NOT PRESENT		
	Eocene	Piney Point Formation Nanjemoy Formation	Marine sediments; dark gray and greenish-gray clay, silt and sand with glauconite	
	Paleocene	Rancocas Group: Vincentown Formation Hornerstown Sand		
Cretaceous	Upper Cretaceous	Mount Laurel Sand	Marine sediments; dark gray and greenish-gray clay, silt and sand with glauconite	14.34
		Matawan Group: Marshalltown Formation Englishtown Formation Merchantville Formation		
			Transition zone	
	Lower Cretaceous	Magothy Formation Potomac Formation	Nonmarine sediments; gray and white quartz sand interbedded red, gray purple, brown yellow silt and clay	

types range from igneous through high-rank to low-rank metamorphic. These include gneiss, schist, marble, slate, phyllite and limestone. Figures 8 and 9 show the locations of the bedrock formations and the principal deposits of glacial outwash, respectively.

Consolidated Rocks -

On the Moosehead Plateau, comprising the northwestern 40 percent of the state, the intensity of metamorphism of the rocks increases southeastward. Nearly unmetamorphosed limestone, sandstone, and shale near the northwestern border with Canada grade into slate, marble, and quartzite, with occasional intrusive granite and diabase north of Moosehead Lake.

South of Moosehead Lake, high-rank metamorphic and meta-igneous rocks occur more frequently. Wells in bedrock on the Moosehead Plateau generally yield reliable domestic supplies. Where greatly fractured or only slightly metamorphosed, the consolidated rock aquifer may yield sufficient water for small industries. Yields of as much as 300 gpm have been reported for wells penetrating the low-degree metamorphosed limestone. [4)]

The Aroostook Valley area occupies the northeastern edge of the state. The intensity of metamorphism as reflected in the rocks is less systematic here, but generally metamorphism increases from north to south. Wells in the igneous and metamorphic rock usually yield less than 10 gpm. In the limestone and marble, well yields are relatively high when solution channels are present. Of 317 bedrock wells in the Lower Aroostook River basin, reported yields range from less than one to 560 gpm. [16)] In the Meduxnekeag River-Prestile Stream basin, the range for 137 wells is from less than one to 400 gpm. [17)]

The Central Uplands region occurs as a broad band of rolling and hilly terrain across the center of the state. Its geologic sequence, in a line from east to west, is similar to that of the north-south sequence in the Moosehead Plateau. The bedrock well yields are usually sufficient for domestic and small municipal and industrial supplies. Carbonate rocks are not as extensive in this region as compared to the Moosehead Plateau. Of 186 wells reported in the lower Kennebec River basin, the yields range from less than one to 67 gpm and the median is seven gpm. [18)]

In the Coastal Lowlands, where the population of Maine is concentrated, igneous and metamorphic gneiss, schist, and

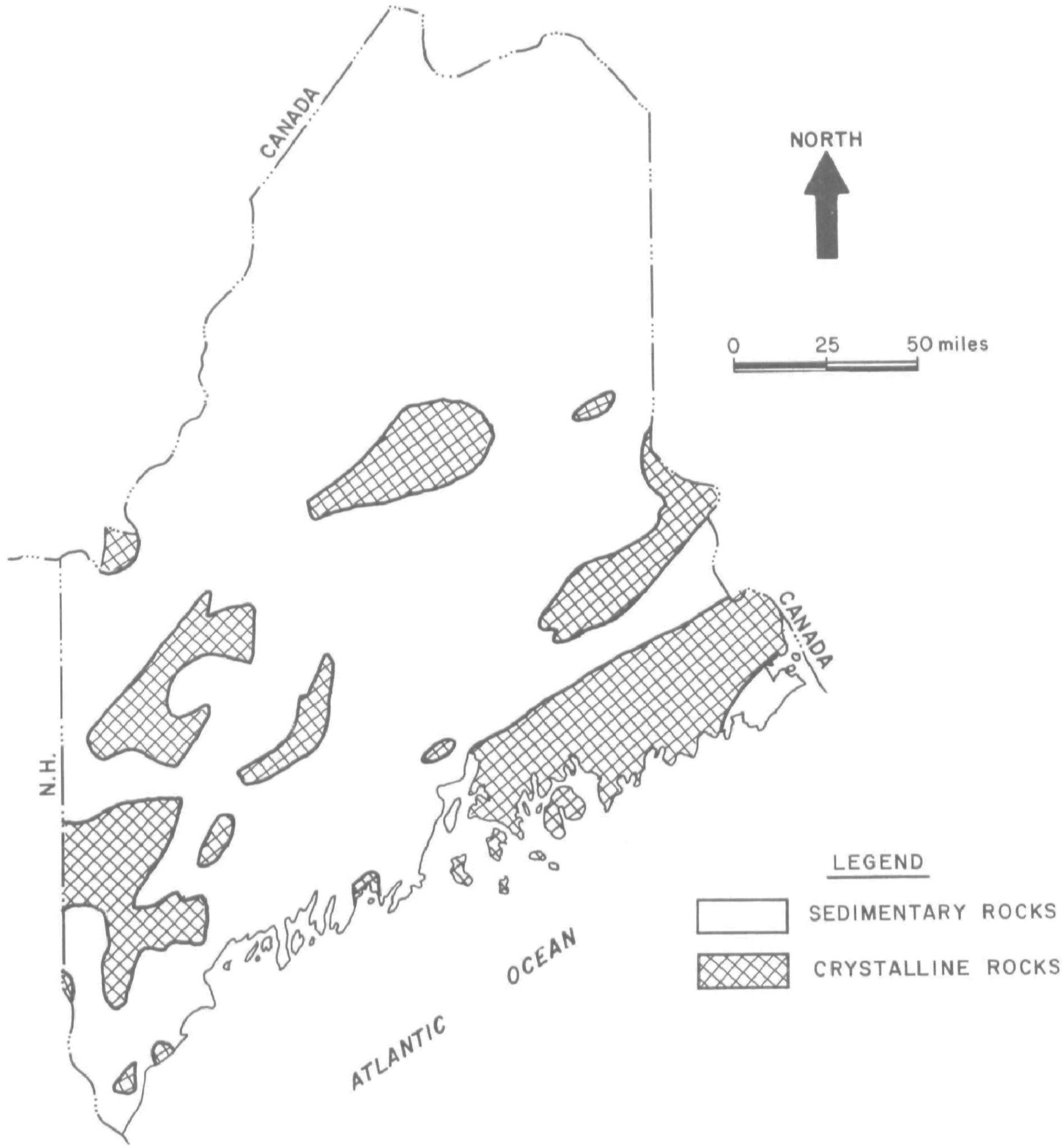

Figure 8. Generalized geologic map of Maine showing principal bedrock aquifers [15)]

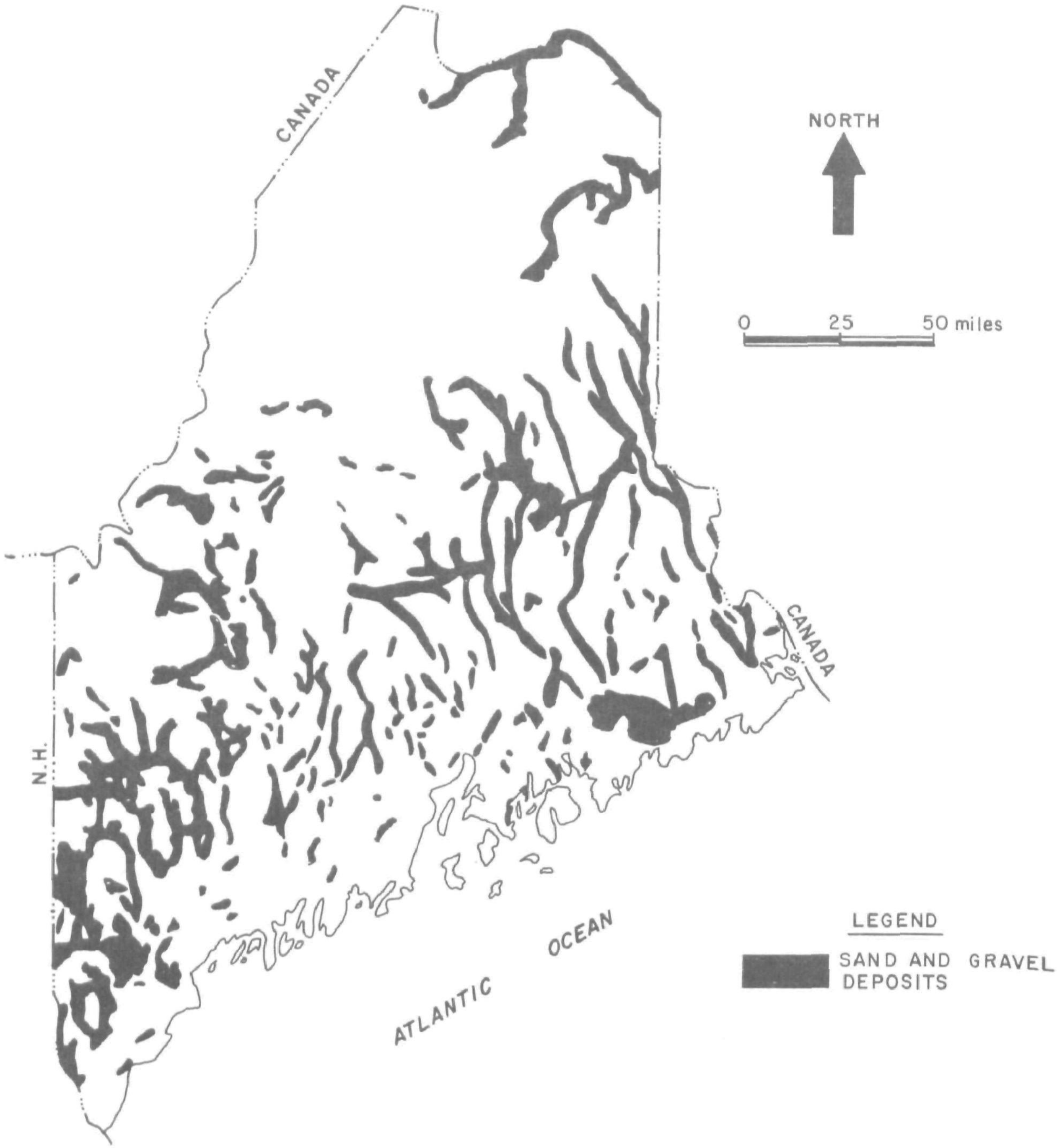

Figure 9. Location of principal sand and gravel deposits in Maine [15)]

pegmatite are more abundant than slate and shale. In this area, reported bedrock well yields range from less than one to 150 gpm with a median of about five gpm.[19,20,21)]

Unconsolidated Deposits -

Four large sand and gravel areas are found in Maine: in the southwest and west central region southwest of Moosehead Lake; in the east central area in southern Aroostook County and eastern Penobscot County; in the St. John River valley southeast of the Canadian border; and in the Aroostook River valley. Only limited data are available on the yields and depths of wells in sand and gravel. Individual wells tapping these aquifers might be expected to yield from a few to upwards of 1,000 gpm and depths would rarely exceed more than 150 feet.[4,18,19,20,21)]

Maryland

Based on Thomas's classification of ground-water regions, Maryland includes portions of the Coastal Plain, Unglaciated Appalachians and a small segment of the Unglaciated Central Region, which is located in the northwest corner of the state. Because this latter region contains a relatively minute land area, it is included in the general discussion of the Unglaciated Appalachian Region. From a ground-water standpoint, the basic difference between the two major regions is that aquifers in the Coastal Plain are unconsolidated, whereas those in the Unglaciated Appalachians are consolidated. Figure 10 shows the locations of the two major ground-water regions, separated by the Fall Line.

Consolidated Rocks -

The Unglaciated Appalachians contain rocks of Precambrian, Paleozoic and Mesozoic (Triassic) age. The eastern portion of the region contains crystalline igneous and metamorphic rocks, including gneiss, slate, phyllite, schist, marble, granite, and gabbro. These are weathered and decomposed to depths greater than 100 feet in some locales; the average depth of weathering is about 40 to 50 feet.[23)] Well yields in this region are usually around five to 10 gpm.[24)] However, higher yields are obtained locally in fault zones, and in the lowlands where the overburden and weathered rock zones are thick.

To the west are found two distinct Paleozoic age sequences of limestone, dolomite, and shale, separated by Precambrian crystalline and Triassic sedimentary rocks. The crystalline rocks include meta-basalt, meta-rhyolite, granodiorite, and

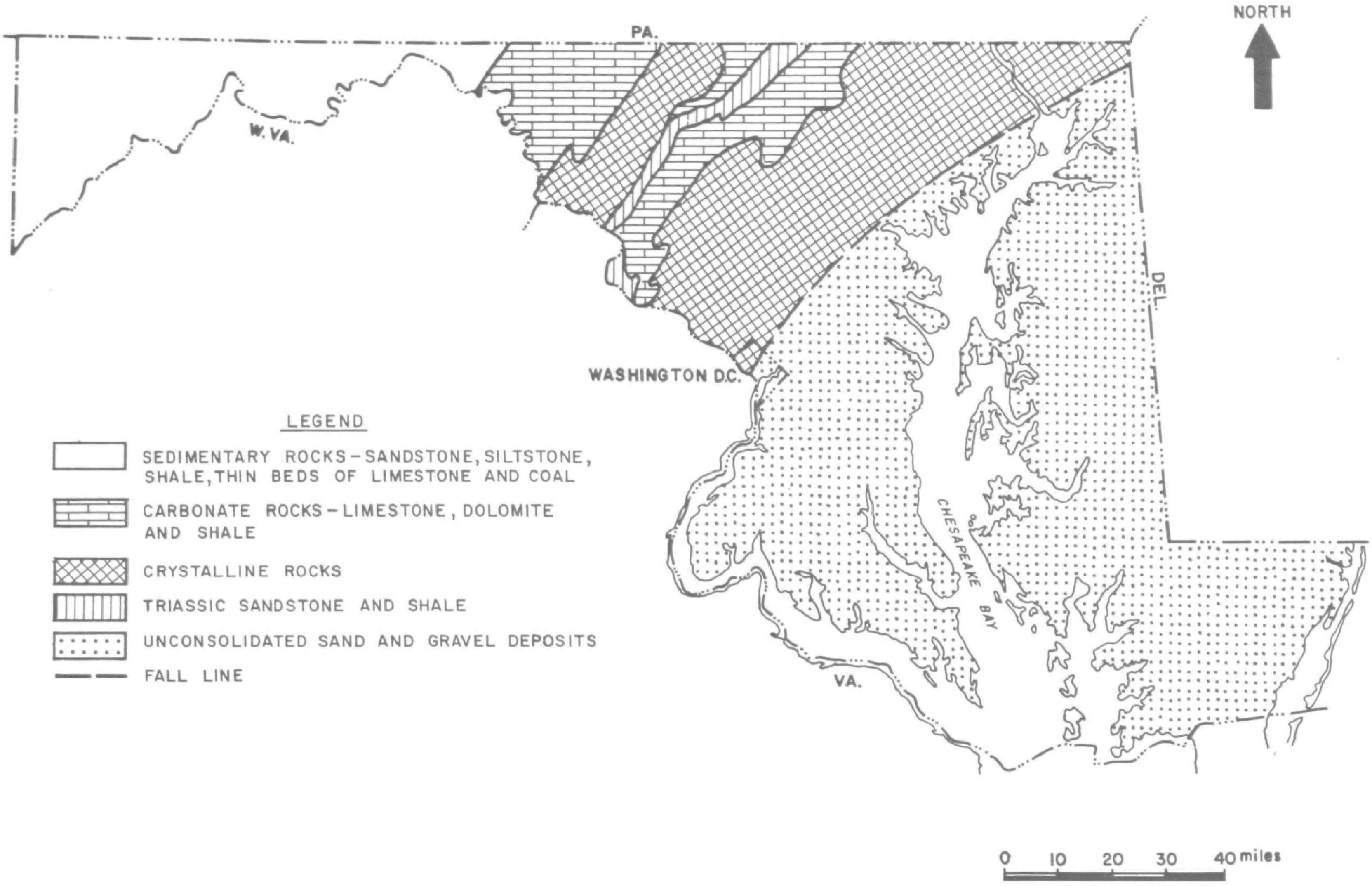

Figure 10. Generalized geologic map of Maryland showing principal aquifers 22,23,24)

granite gneiss, which form the highlands. About 18 percent of the wells in this area yield less than five gpm.

Triassic rocks overlie the limestone. The sequence varies in width from less than a mile to as much as 15 miles, and consists primarily of shale, siltstone, and sandstone. Well yields are variable; the highest reported yield of 300 gpm was obtained from a well penetrating a fractured sandstone stratum. Nine wells in shale yielded an average of 1.5 gpm. 25)

In the lowlands bordering the crystalline rocks, the thick sequence of carbonate rocks has been subjected to complex folding and faulting. The carbonates are good aquifers, with high-yielding wells found in fault areas, and at shallow depths where there has been development of solution cavities. Wells generally range between 100 and 300 feet in depth, and indications are that increases in yield are severely limited with greater depths. Some limestone wells yield as much as 400 gpm, and a limestone spring discharging 3,000 gpm has been reported. 4)

The western part of the state contains sedimentary rocks of Ordovician to Pennsylvanian age: sandstone, siltstone, and shale, with thin beds of limestone and coal. These rocks were subjected to folding and faulting, particularly in the central and eastern portion. They decrease in permeability below depths of a few hundred feet. Well yields are generally less than 10 gpm, although higher yields are obtained in the faulted areas. Water occurs mainly in fractures, but some of the sandstone strata are porous, which adds significantly to the water availability and the yields of wells.

Unconsolidated Deposits -

The unconsolidated deposits of the Coastal Plain form a wedge-shaped mass that starts at the Fall Line and thickens to the southeast. These deposits overlie a crystalline rock complex and consist of sand, gravel, silt, clay, marl, and shell beds ranging in age from early Cretaceous to Holocene. They attain a thickness of nearly 10,000 feet along a portion of the Atlantic Coast. Various formations outcrop in a sequence from the oldest to the youngest in a southeastward direction. The succession of deposits is generally similar to that found in Delaware.

Coastal Plain deposits are thin along the Fall Line, and yields from wells are generally lower than those from wells located further east. To the east, well yields range from a few hundred gallons per minute to as much as 1,200 gpm on the western shore, and as much as 1,700 gpm on the eastern shore of Chesapeake Bay. Table 6 summarizes the geologic units of the Coastal Plain and describes their water-bearing properties.

Massachusetts

Massachusetts is located within the Glaciated Appalachians region. Physiographically, the state consists of four principal divisions, the mountainous, western Glaciated Appalachians (known locally as the Berkshires), a central upland Piedmont, the Triassic Lowland, and the Coastal Plain of Cape Cod and associated coastal areas.

Figure 11 is a generalized geologic map showing the six major aquifers in Massachusetts. Four of these are composed of consolidated rocks: crystalline rocks, Hoosic-Housatonic Valley carbonate rocks, coastal basin sedimentary rocks, and Connecticut Valley sedimentary rocks. Two unconsolidated aquifers also occur: unstratified till, and sand and gravel.

Crystalline Rocks -

The most areally-extensive bedrock aquifer is the crystalline rock complex: a broad spectrum of igneous and metamorphic types ranging in age from Precambrian to Carboniferous(?). They are generally similar in water-bearing characteristics, with well yields usually sufficient for domestic supplies. Occasional yields of 30 to 40 gpm, adequate for small-scale industrial and municipal use, and a few yields of 100 to 200 gpm have been reported. However, the median yield of wells in the crystalline aquifer is about 10 gpm. Well depths range between 100 and 200 feet. [28 through 35)]

Carbonate Rocks -

In western Massachusetts, the valley of the Hoosic and the Housatonic Rivers is underlain principally by carbonate rocks, which continue southward into Connecticut and possibly northward into Vermont. Occurring between hills of predominantly gneiss and quartzite to the east and schist to the west, these units of limestone and dolomite represent a productive aquifer in this portion of the state. The yields of wells are controlled to a great extent by the size and number of solution channels encountered. In Berkshire County, well yields ranged from less than one to 1,700 gpm with a median of nine gpm. [29)]

Table 6. GEOLOGIC UNITS AND THEIR CHARACTERISTICS IN THE MARYLAND COASTAL PLAIN PROVINCE.[23,24,26]

System	Series	Stratigraphic units		Generalized lithologic character	Water-bearing properties
Quaternary	Holocene	-		Soil, sand, peat and silt	Small yields to shallow wells
	Pleistocene	Columbia Group undivided		Sand, silt, gravel and clay	Important aquifer with localized high permeability, well yields up to 1,500 gpm
Tertiary	Pliocene	Brandywine Formation		Clay, sand and gravel	Limited areal extent along the Fall line
	Miocene	Chesapeake Group	Yorktown Formation	Gray, fine to medium sand, gray or blue clayey silt	Sand section yields fair amounts of water, locally high in iron, functions as a semiconfining layer
			St. Mary's Formation	Clay, silt, fine sand, shells	Functions chiefly as a confining layer
			Choptank Formation	Gray and green silt and clay, some shells and fine sand	Low yield to wells, locally hard and high in iron
			Calvert Formation	Gray and blue silt and clay, shells, some sand	Locally yields moderate quantities of water, occasionally highly mineralized, primarily a confining layer
	Oligocene	SECTION NOT PRESENT			
	Eocene	Piney Point Formation		Dark gray to green sand, silt and clay	Important artesian aquifer, well yields up to 1,200 gpm, downdip section probably saline
		Nanjemoy Formation		Black to green glauconitic sand, silt and clay	Confining layer, saline in southeast
	Paleocene	Aquia Formation		Green glauconitic sand, clay and shells	Locally an important aquifer, moderate well yields up to 250 gpm
		Brightseat Formation		Gray to green fine to coarse sand and clay	Limited areal extent and thickness

Table 6 (Continued). GEOLOGIC UNITS AND THEIR CHARACTERISTICS IN THE MARYLAND COASTAL PLAIN PROVINCE.[23,24,26)]

System	Series	Stratigraphic units		Generalized lithologic character	Water-bearing properties
Cretaceous	Upper Cretaceous		Monmouth Formation	Green glauconitic sand, gray clay, shells	Confining layer, saline in downdip section
			Matawan Formation	Black clay and brown sand	Chiefly a confining layer, locally used as an aquifer
			Magothy Formation	White, yellow and gray sand with gray and brown clay	Well yields of up to 600 gpm, saline in downdip section
			Raritan Formation	Gray fine grain sand, gray, brown and red clay	An aquifer with saline water in downdip section
	Lower Cretaceous	Potomac Group	Patapsco Formation	Clay, shale, white, gray and green sands	A limited aquifer in the sandy zones, saline in downdip section
			Arundel Formation	Dark gray and maroon clay	Limited in areal extent, chiefly a confining layer
			Patuxent Formation	Fine to very coarse sand, gray, brown and green shale	Not developed, limited information available, saline water thought to be present downdip

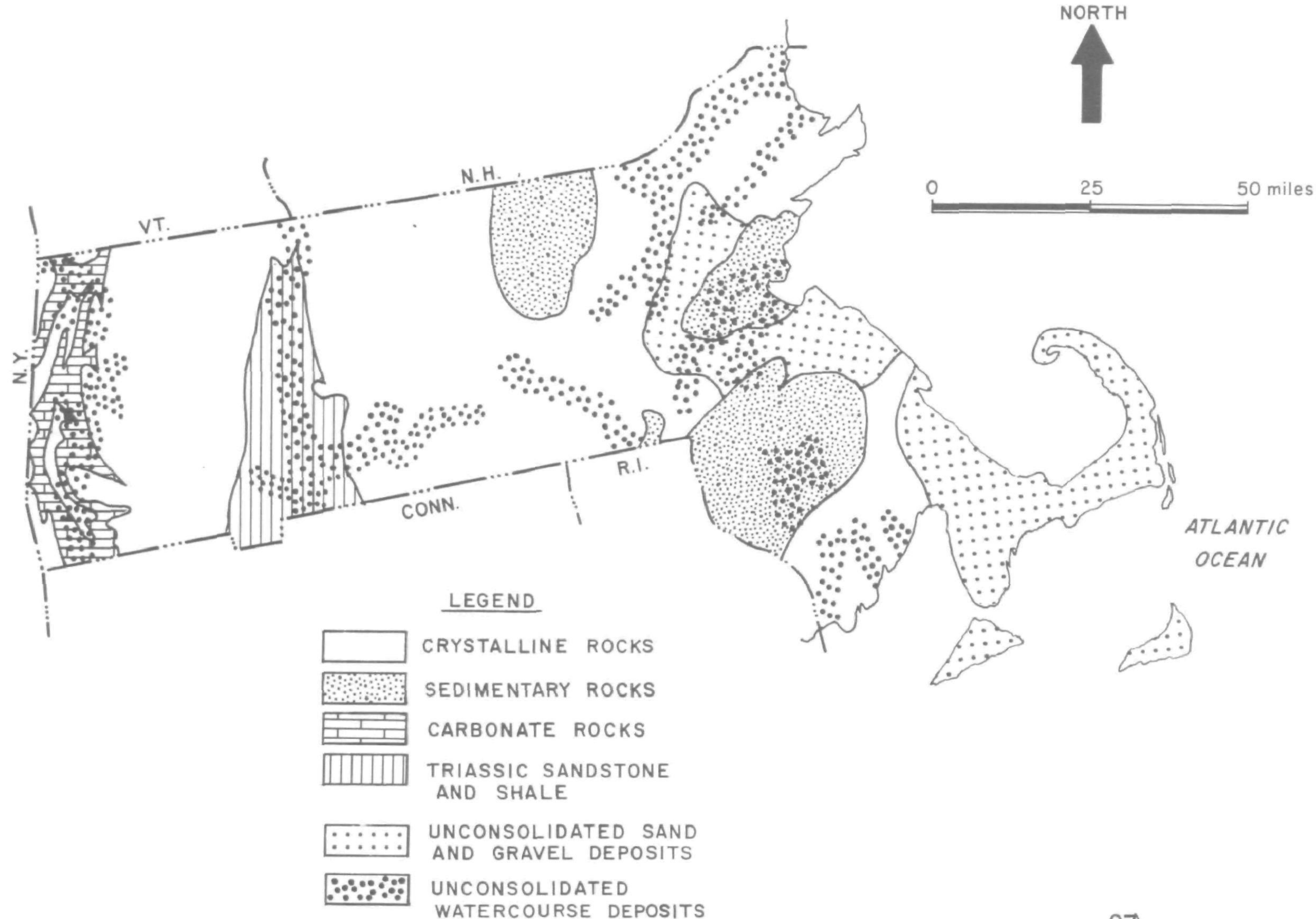

Figure 11. Generalized geologic map of Massachusetts showing principal aquifers 27)

Coastal Basin Sedimentary Rocks -

Within the crystalline terrain in southeast and northeast Massachusetts, portions of the upper bedrock consist of sedimentary rock units. The dominant rocks, dated as Carboniferous(?), are clastics, such as sandstone, shale, and conglomerate, metamorphosed to varying degrees. They were originally deposited in sedimentary basins; the two largest are the Narragansett and the Boston. Some minor outcrops of similar age rocks occur throughout Rhode Island and eastern Massachusetts.

Little data are available on yields from wells in these rocks. For one area, yields reported for 92 wells range from one to 170 gpm, with a median yield of eight gpm. [36]

Connecticut Valley Sedimentary Rocks -

In the central part of the state, Triassic age rocks occupy a tectonic basin along the trend of the Connecticut River. These rocks are primarily sedimentary: sandstone, shale, and conglomerate, with minor limestone and intruded diabase. The rock types and structures are similar to those found in Triassic basins in Connecticut, Pennsylvania, New Jersey, and Maryland.

Little specific ground-water data are available on the Triassic age rocks of Massachusetts. For 63 wells believed to be finished in Triassic rocks, the yields ranged from less than one to 760 gpm, with an average of 41 gpm, and a median of 12 gpm. [37]

Till and Fine-Grained Stratified Deposits -

Extensive deposits of unstratified glacial drift, called till, cover the bedrock over most of the state. Till generally has a low permeability and for that reason is normally a poor aquifer. During prolonged periods of drought, wells in till frequently go dry. However, it is still a useful aquifer in many areas because of its accessibility. Well yields are typically about one to two gpm.

Where stratified deposits of fine-grained material are found, the water-yielding characteristics may be similar to those of till. Eolian, marine-swamp, and lacustrine deposits are typical fine-grained stratified units.

Sand and Gravel Deposits -

The most prolific aquifers in Massachusetts are the unconsolidated stratified deposits, predominantly sand and gravel. There are three major types of sand and gravel deposits, all composed of water-borne material. They were deposited in contact with glacial ice during the Pleistocene Period, as outwash in drainage areas of the melting glaciers, or as alluvial materials associated with streams not related to glaciation.

Sand and gravel deposits are common in many areas of the state, particularly in the southeastern portion and on Cape Cod. Slightly different water-yielding characteristics for ice-contact and outwash deposits are observed, even where all wells are in the same drainage basin (Table 7). Yields of wells in ice-contact deposits are generally higher than those in outwash deposits in the same area. However, yields of wells from outwash relative to yields of wells from ice-contact deposits do seem to improve toward the east and south. Outwash is thicker and more extensive in the northeast and southeast portions of the state.

New Hampshire

New Hampshire is located within the Glaciated Appalachians region. Figure 12 is a generalized geologic map of the state showing the principal aquifers.

Consolidated Rocks -

Within New Hampshire, the upper bedrock is composed of a full suite of rock types. Approximately two-thirds of the state is underlain by sedimentary and volcanic rocks of middle-Paleozoic age which have been metamorphosed to varying extents; the remaining one-third is underlain principally by middle and late Paleozoic intrusives. [4] For hydrogeologic purposes, all of these rock types may be considered as one unit. At present, sufficient ground-water studies have not been completed to distinguish between the water-yielding properties of various rock types.

Wells were inventoried in 228 towns in New Hampshire by G. W. Stewart; approximately 80 percent of the wells penetrated bedrock. [39] In the southeastern area, drilled wells penetrating bedrock yield small to moderate quantities of water suitable for domestic and small industrial use. [40] In the lower Merrimack River valley, yields are similar to those in the southeast. [41] In one report, it was noted that of 1,482 wells for which a yield was reported, the median was

Table 7. YIELDS AND DEPTHS OF SELECTED WELLS IN SAND AND GRAVEL DEPOSITS IN MASSACHUSETTS. [30,32,33,35,36,38)]

Drainage basin	Type of deposit	Reported number of wells	Range in yield (gpm)	Median yield (gpm)	Reported number of wells	Range in depths (feet)	Median depth (feet)
Housatonic River	Outwash	N	<1 - 600	N	N	N	N
	Ice-contact	N	<1 - >900	N	N	N	N
Millers River	Outwash	13	2 - 273	22	N	N	N
	Ice-contact	43	1.5 - 720	31	N	N	N
Assabet River	Outwash	6	6 - 70	11	40	3 - 112	40
	Ice-contact	56	3 - 300	40	178	2 - 115	25
Ipswich River	Outwash	28	7 - 690	34	217	5 - 90	16
	Ice-contact	128	7 - 718	40	363	8 - 80	21
Parker River and Rowley River	Outwash	3	<1 - 76	14	23	5 - 51	21
	Ice-contact	18	<1 - 500	17	55	7 - 115	39
Taunton River	All types of sand and/or gravel	373	2 - 900	40	408	7 - 173	45

N - Not reported

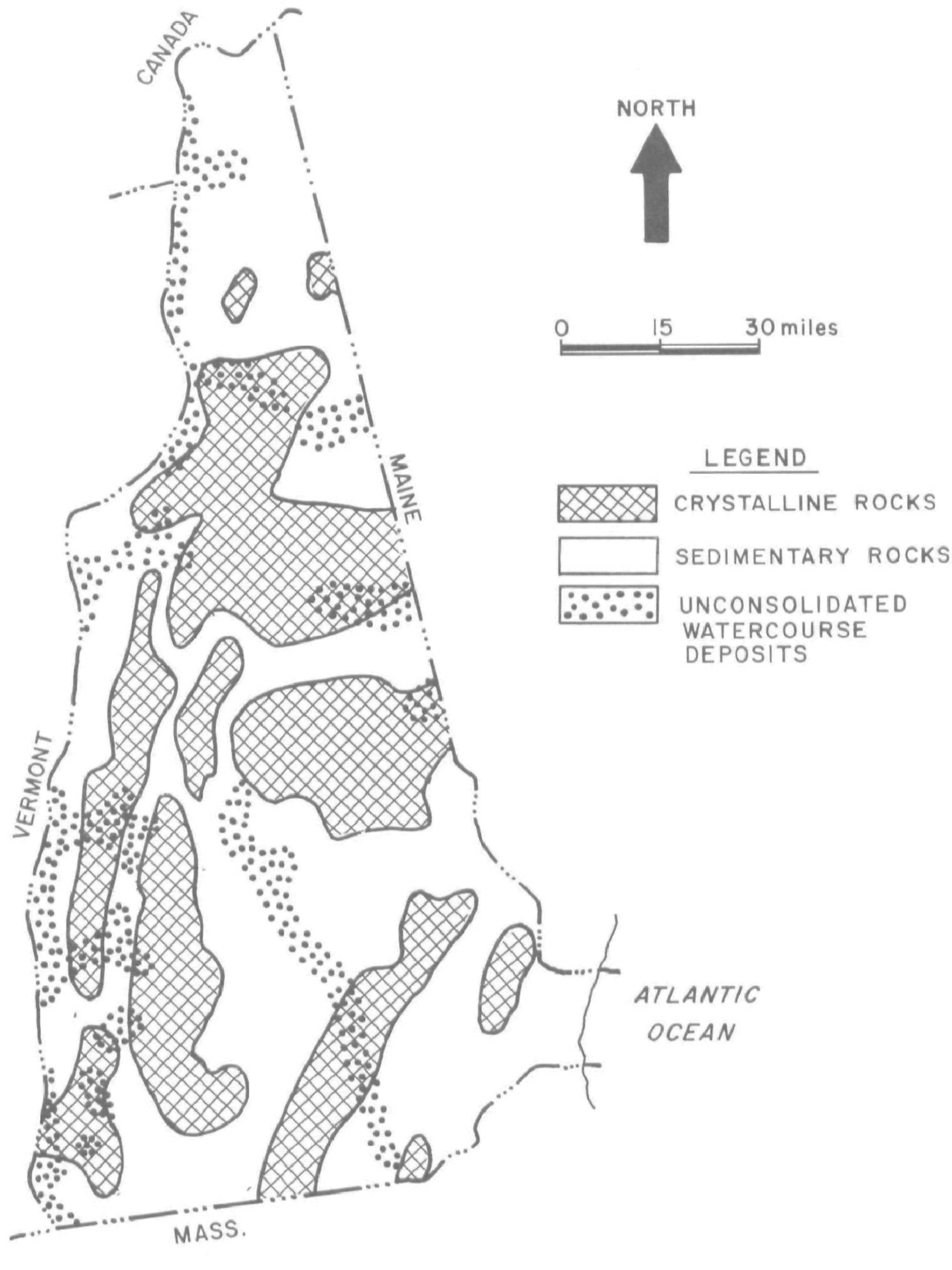

Figure 12. Generalized geologic map of New Hampshire showing principal aquifers [27)]

6.5 gpm; most of these wells penetrated bedrock. [42]

Unconsolidated Deposits -

Sand and gravel comprise the major water-yielding unit, occurring mainly as outwash deposited by melt waters from Pleistocene glaciation, and as outwash and alluvium deposited in narrow stream valleys during late Pleistocene glacial, post-glacial, and recent times. Minor sand and gravel deposits occur as kames, eskers, and lenses of sorted material within till.

Long-term yields are limited by the thickness and extent of the deposits. The best yields usually occur in wells adjacent to perennial streams, where pumping may induce surface water into the aquifer. Available information suggests that yields of a few hundred gpm are common. [40,41] The deposits are reported to be as much as 200 feet thick. [40]

New Jersey

Segments of three ground-water regions are found in New Jersey: the Unglaciated Appalachians, the Glaciated Appalachians, and the Coastal Plain. [1] The rock types and water-bearing characteristics are different among the regions, and from location to location within the same region. The major aquifers northwest of the Fall Line are mostly consolidated rocks, while those to the southeast are unconsolidated deposits. Figure 13 is a generalized geologic map of the state, showing the principal water-bearing rocks.

Consolidated Rocks -

The northwestern portion of the state is characterized by broad valleys and ridges containing rocks composed of limestone, shale, sandstone, and quartzite of Early Paleozoic age. Glacial deposits cover most of these rocks and, in some areas in the major stream valleys, are thick and permeable enough to be important aquifers. The sandstone and quartzite strata are poor aquifers, partially because of their irregular and variable thickness but primarily due to the lack of major fracturing. Where these rocks are found, the average thickness is 50 to 100 feet. However, in many areas, they are completely absent. [44] Wells penetrating these rocks usually obtain water at the contacts with overlying or underlying formations.

The major aquifer is the Kittatinny Limestone. It is composed primarily of dolomite, but the distinction between limestone and dolomite is of no importance with regard to

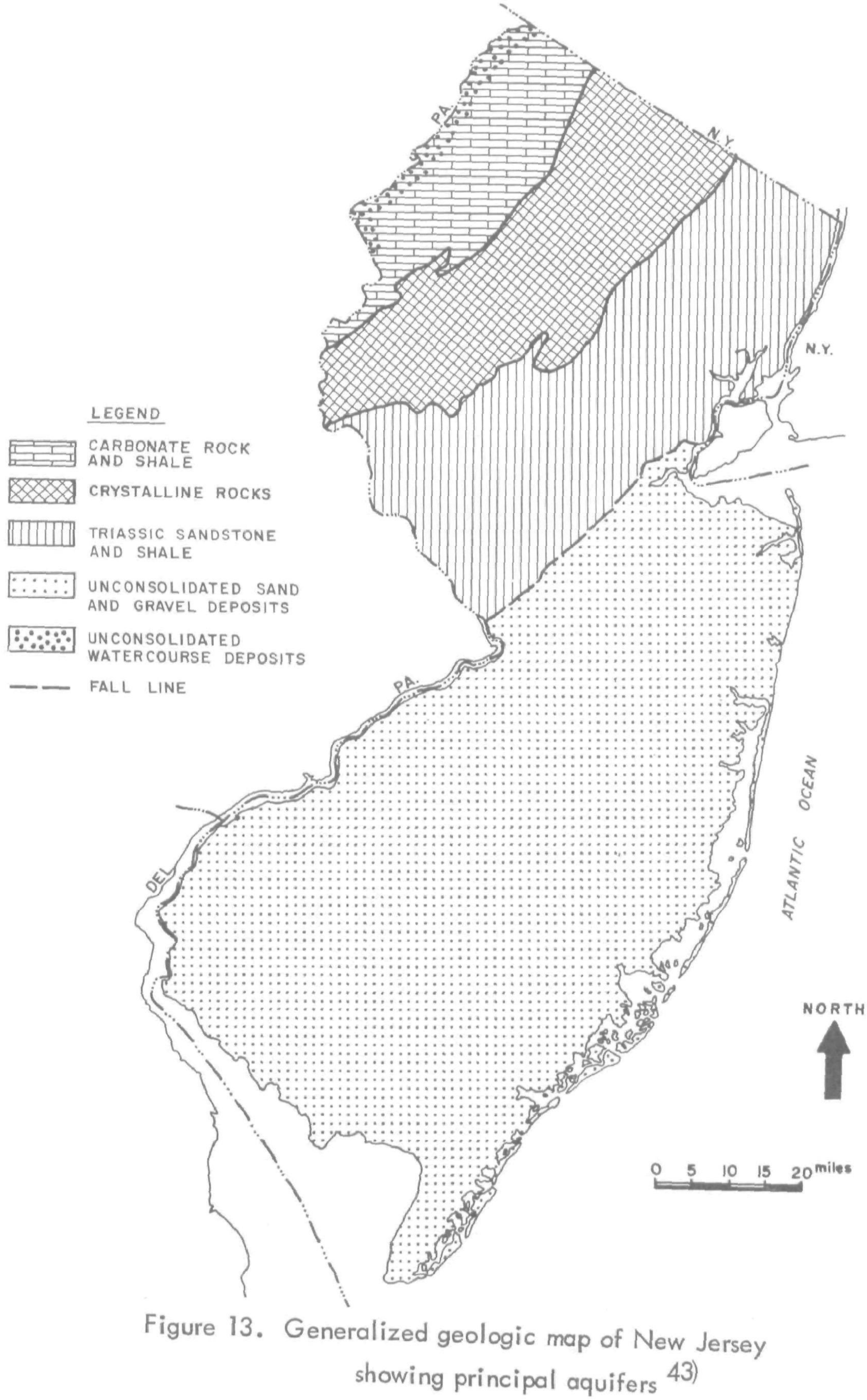

Figure 13. Generalized geologic map of New Jersey showing principal aquifers 43)

hydrologic characteristics. Some large solution cavities are present, in addition to vugs and fractures. Well yields are highly variable from one location to another, with many in excess of 100 gpm.

In the northwest, the most extensive formation areally is the Martinsburg, which consists of a thick sequence of shales, slates, and sandstone. Generally, these rocks are poor aquifers, with well yields averaging a few gpm. However, wells penetrating fault systems can yield several hundred gpm.

To the east, the belt of Precambrian rocks consists primarily of gneiss, schist, and granite. Typical well yields are in the range of five to 10 gpm, with only those wells located near major fracture systems having substantially higher yields. 4)

Further east, Triassic age sandstone, shale, argillite, traprock, and local occurrences of conglomerate are found. The Stockton sandstone is a good aquifer with some primary porosity, especially in the poorly cemented sections. However, the lower section is typically well cemented with only minor fractures.

The Brunswick shale constitutes the bulk of the rock of Triassic age. It has a low porosity, but locally well-developed fractures are known to occur and may extend to a few hundred feet in depth. Well yields are generally greater than 100 gpm. The Lockatong argillite is an accumulation of fine-grained lake deposits. It is dense, very hard, and forms the crests of ridges because of its resistance to erosion. The formation is a poor aquifer with very low porosity and few joints. Wells tapping this formation have low yields.

Basalt and diabase rocks, known as traprock, are also found in the Triassic section. The basalt was formed by a series of lava flows, and the diabase intruded as a sill, a portion of which makes up the Palisades bordering the Hudson River. The sill is extremely tight with only minor joints. Well yields from these units are generally only a few gpm.

Unconsolidated Deposits -

Unconsolidated deposits of Pleistocene age cover a major portion of the Triassic rock area, with the southernmost terminal morraine dividing it almost in half. The northeast portion contains mostly fine-grained lake deposits and till, with some scattered deposits of glacial outwash. In the southwest, glacial outwash is found in the southwest-trending valleys. Wells tapping thick and permeable outwash deposits frequently have yields in excess of one mgd.

The Coastal Plain region south and east of the Fall Line incorporates about three-fifths of the state. The unconsolidated deposits consist of sand, gravel, clay, silt and marl, forming a wedge-shaped mass which thickens to the southeast. They attain a thickness of over 6,000 feet, with an average dip of about 100 feet per mile. [45] The sequence of deposition is similar to that of Delaware and Maryland.

Of the total thickness of the Coastal Plain deposits, approximately half is made up of non-marine sediments of Cretaceous age forming the basal part of the section. Overlying these sediments are marine deposits of late Cretaceous to early Tertiary age, which attain a thickness of over 1,000 feet. These in turn are overlain by a sequence of marine and non-marine deposits of late Tertiary age, which attain a thickness of about 1,000 feet. Quaternary age sediments blanket the older deposits and, in some buried channels, are 200 or more feet thick. [45]

The most productive and developed aquifers are the Raritan and Magothy formations of Cretaceous age, with well yields of 500 gpm or more. Several other important Cretaceous aquifers are the Englishtown, Wenonah, Mount Laurel, and Red Bank Sand formations. Well yields in these aquifers are commonly 100 gpm or more, with some yields up to 500 gpm. [4]

The Tertiary sequence contain some formations that are important aquifers, including the Vincentown, Kirkwood, and Cohansey formations. Moderately-high well yields are common. The Quaternary deposits are important aquifers locally, particularly along the coast and the Delaware River.

New York

The geology of New York is as varied as that of any state in the study area. Basically, however, the rock types of New York may be classified into six hydrogeologic units based on similar water-bearing characteristics (Figure 14). These units include crystallines; shales; sandstones; and carbonate rocks; as well as glacial and pre-Pleistocene Coastal Plain deposits.

Crystalline Rocks -

The crystalline rocks in New York are the most complex and variable of all the rock groups in the state. The component

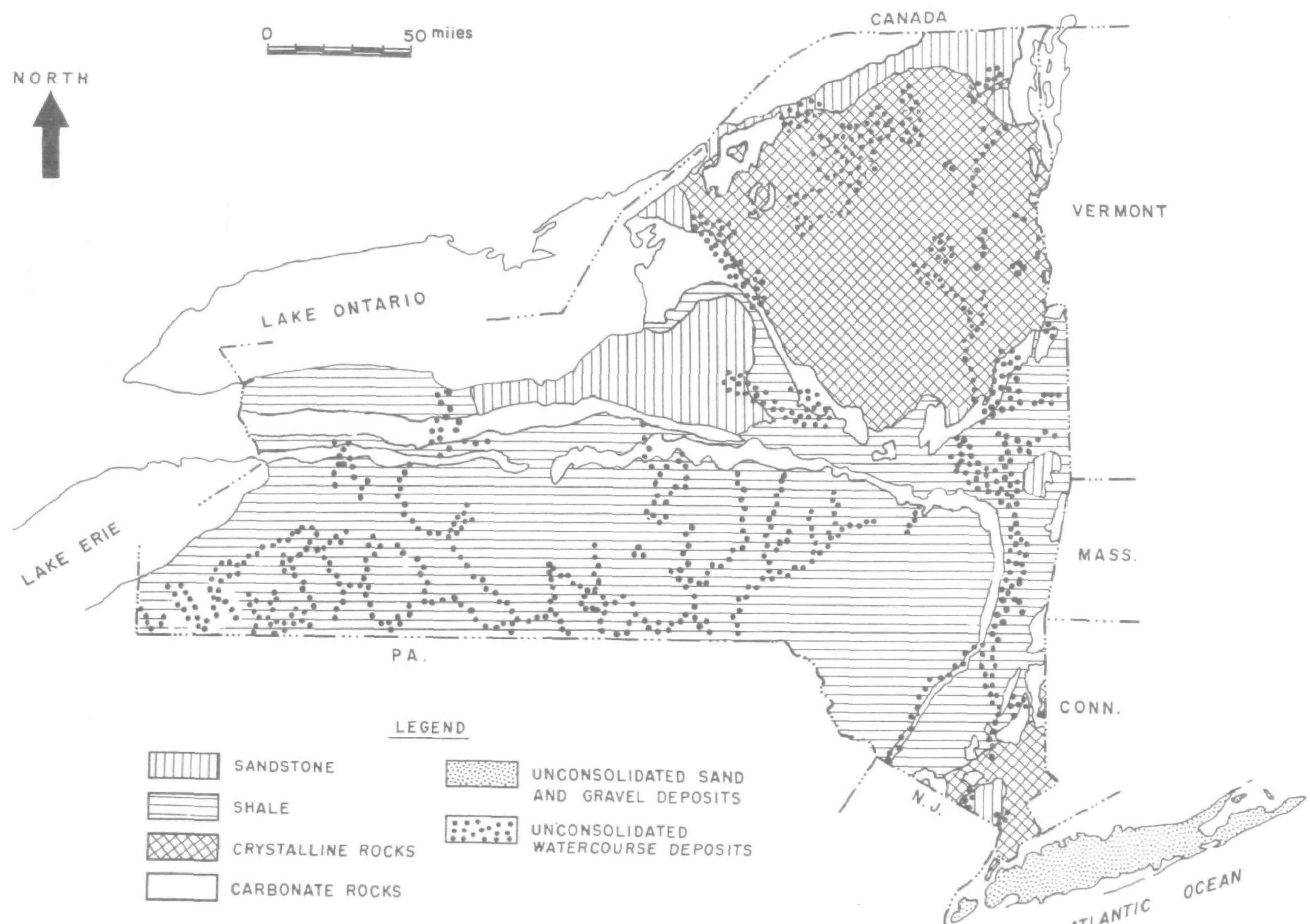

Figure 14. Generalized geologic map of New York showing principal aquifer [46]

rocks are primarily metamorphosed sedimentary and igneous units and are the oldest in New York. Most have been subject to many periods of deformation and recrystallization.

Crystalline rocks outcrop almost exlusively in two areas of the state. The largest portion is found in the northeast, where a blocky mass of granite, gneiss, and schist forms the Adirondack Mountains. The other major outcrop area occurs in the southeast, where crystalline rocks underlie most of New York City and its northern suburbs.

Despite the complex geology and structure of the crystalline rocks, they exhibit very similar water-bearing characteristics, and can be lumped into one hydrogeologic unit. The crystalline rock aquifer is acknowledged to be the least productive bedrock unit in the state.[46] Yields of from one to 10 gpm are common.

Shales -

The areas designated as shale in Figure 14 actually include shale, slate and a low-rank, metamorphosed rock usually described as schist. Shale is the predominant unit in the areas so mapped, but interbeds of sandstones, limestones, and evaporites commonly occur. Except in the easternmost part of the state, the shale is only moderately folded and faulted.

Typically, well yields are sufficient only for domestic and small industrial supplies (a few to several tens of gpm). Exceptions may occur where a well drilled into shale has a source of adequate recharge, such as an adjacent surface-water body or thick overlying unconsolidated deposits. Large yields (up to 3,000 gpm) reported for wells penetrating the Salina Group in the Buffalo area are probably due to induced recharge from major streams in the area.[47]

Sandstones -

Sandstone constitutes the upper bedrock surface over two broad areas: in the northeastern region flanking the northern limit of the Adirondacks, and in the central region forming an upland area skirting the southeast shore of Lake Ontario. Isolated sandstone units occur in the extreme east-central region of the state in the Taconic Mountains east of Albany, and in the southeastern region in Rockland County.

The sandstone aquifer, though fairly productive, is not used extensively because of a number of factors. First, this resistant rock forms uplands which are not conducive to residential and commercial development. Also, surface-water sources and better aquifers are often available in the same area. As with the crystalline and shale aquifers, the frequency of fractures, faults, and bedding planes, along with a good source of recharge, primarily determine yield of wells of sandstone aquifers. Where the material cementing sand grains is calcitic, solution channels often increase permeability.

Yields of wells tapping sandstone are typically 10 to 15 gpm. However, in Rockland County (southeastern region), 265 wells penetrating the Newark Group of Triassic rocks (in which sandstone is the predominant water-bearing unit) range in yield from three to 1,515 gpm; the average yield is 80 gpm and the median 30 gpm. 48) Selected public-supply wells tapping these rocks have an average yield of 300 gpm for 25 wells. 48)

Carbonates -

The carbonate rocks as a whole are the most productive bedrock aquifers in New York. There are three types of carbonate rocks: limestone, dolomite, and marble, all of which have similar water-bearing properties.

Three major carbonate rock areas in New York are considered. The first area outcrops on the flanks of the Adirondacks in the northeast. Usually outcropping in valleys eroded by streams flowing off the Adirondack highlands, the carbonate aquifer in this section is rarely used for more than domestic supply because of the availability of good quality surface-water sources. Individual well yields, depending upon the carbonate unit tapped, average from nine to 35 gpm. 49, 50,51)

A second important carbonate-rock area occurs as two bands 10 to 20 miles apart across the western and central portions of the state. The southernmost band can be traced eastward to the Hudson River valley, where it flanks the northeastern Catskills and trends southwest toward the juncture of New York, New Jersey, and Pennsylvania. Along most of its length, this band is a very important aquifer because it often is the best-producing aquifer in an area of questionable surface-water quality.

The strips of carbonate rock outcropping east to west across the central and western region consist of a northerly band of predominantly dolomite (Lockport formation) and a southerly band of predominantly limestone (Hamilton-Onondaga group). Table 8 illustrates the characteristic yields of wells in these units. Most of the wells in the Buffalo area which exhibit unusually high yields appear to derive much of their water by infiltration from the Niagara River and Tonawanda Creek Basins.

A third area of the state, in which carbonate rock is the principal bedrock aquifer, is in the southeast sector. Here, the carbonates associated with the Appalachian mountain-building have been metamorphosed to varying degrees. Average yields reported for selected wells in Dutchess, Putnam and Westchester Counties are 22, 10 and 40 gpm, respectively. 52,53,54)

Unconsolidated Deposits -

Two types of unconsolidated glacial deposits are present, the most extensive being till. The till deposits vary from a few to several hundred feet thick. Till is not considered to be a productive aquifer other than for domestic supplies.

Sorted deposits, although more limited in areal extent than unsorted deposits, are usually the most productive water-bearing units in the state. However, isolated areas exist in which dune deposits or lacustrine deposits are found. These are generally too thin and/or too fine grained to yield significant quantities of water. They have the general water-bearing characteristics of till deposits.

The most significant water-lain, unconsolidated sediments consist chiefly of sand and gravel which have been deposited under one of the following conditions: a) pre-Pleistocene (pre-glacial) period of erosion of the bedrock uplands; b) during the Pleistocene period when the glacial front was melting and the meltwater was transporting large quantities of sediment, or; c) by large post-Pleistocene streams carrying significant quantities of sediment.

Several areas are found in the state in which productive sand and gravel aquifers afford large-scale diversions. In the Lake Champlain-Upper Hudson River Basin, along the lower Hudson River Valley (a band along the eastern border 30 miles wide), and throughout the central and western portions of the state, sand and gravel are found in the major drainage systems, especially those trending north-south. Table 9 provides data on wells tapping non-Coastal Plain sand and gravel deposits.

Individual sand and gravel aquifers in central and western New York have been reported to have available yields as

Table 8. RANGE IN AND MEDIAN YIELDS OF SELECTED WELLS IN CARBONATE ROCKS IN THE CENTRAL REGION. [41,55,56,57]

Area	Rock Unit	Number of wells reported	Range (gpm)	Median (gpm)
Syracuse vicinity	Dolomite	13	1 - 30	4
	Limestone	19	3 - 700	25
Rochester vicinity	Dolomite	21	5 - 500	180
	Limestone	81	0.5 - 300	22 [b]
Buffalo vicinity	Dolomite	16	5 - 2,300	200
	Limestone [a]	60	5 - 3,000	323 [b]

a) Combined data from yields of wells finished in two formations.

b) Average

Table 9. RANGE IN AND AVERAGE YIELDS OF SELECTED WELLS IN SAND AND GRAVEL AQUIFERS.[47,48,49,52,53,55,58,59]

Region	Area	Number of wells	Range (gpm)	Average (gpm)
Northeast	Lake Champlain-Upper Hudson	- a)	0 - 400	28 - 38
Southeast	Columbia	51	0 - 350	27 b)
	Dutchess	37	3 - 625	25 b)
	Putnam	55	1 - 450	33
	Rockland	- a)	8 - 1,700	183 b)
West-Central	Rochester area	23	10 - 1,016	287
	Buffalo-Niagara	20	30 - 800	209
Central	Sullivan	40	2 - 700	175

a) Information not provided

b) Median

great as 31 mgd in the Jamestown area and 12 to 20 mgd in the Syracuse area.[60,56] Kantrowitz estimated that all of the sand and gravel aquifers in the central New York area centered about Syracuse had an available yield of 240 mgd although the estimated 1970 withdrawal from all ground-water sources in the area was only 27 mgd.[56]

The area of the most extensive sand and gravel deposits is the Coastal Plain of Long Island and lower Staten Island. Here the bedrock is overlain by deposits of Cretaceous age, which in turn are capped by Pleistocene sediments.

The aquifer system of the Coastal Plain in New York is comprised of four major water-bearing zones more or less separated by confining beds. Yields of from several hundred to a thousand gpm can be developed from individual wells. Well depths are most commonly 300 to 1,000 feet. The available ground water in storage in Long Island's sand and gravel aquifers is estimated at 5 to 10 trillion (million-million) gallons.[61]

Pennsylvania

In Pennsylvania, six basic hydrogeologic units exist (see Figure 15). Each of these is represented by a predominant or characteristic rock type. The units are Precambrian and early Paleozoic crystalline rocks, Cambro-Ordovician carbonate rocks, middle Paleozoic clastic rocks, late Paleozoic sedimentary rocks with coals, Triassic sedimentary rocks, and unconsolidated sand and gravel deposits.

Crystalline Rocks -

The crystalline rocks are the oldest rocks in Pennsylvania. Although extremely variable geologically, they have been grouped into a single hydrogeologic unit based on similar water-bearing characteristics. Found exclusively in the southeastern portion of the state, the crystalline rocks encompass a full suite of igneous and metamorphic rock types, including gneiss, greenstone, serpentine, anorthosite, schist and quartzite. The crystalline rocks have been extensively deformed by tectonic activities associated with formation of the present Appalachian Mountains. The yield of a particular local rock unit is directly related to the degree of deformation.

Ground water in the crystalline rocks is found within fractures and weathered zones under water-table and semi-artesian conditions.[63] Lohman reported that of selected wells in crystalline rock in southeastern Pennsylvania, 50

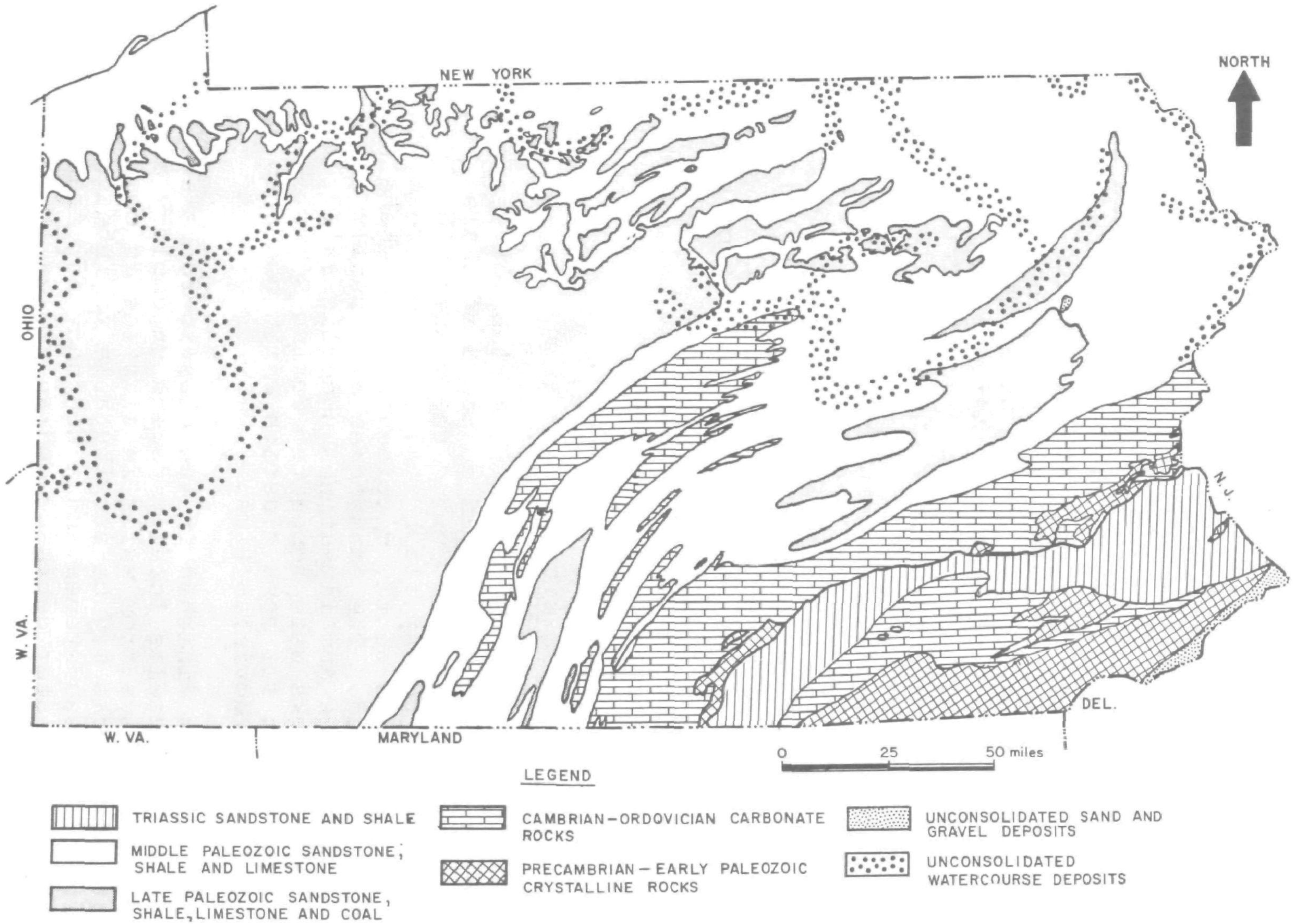

Figure 15. Generalized geologic map of Pennsylvania showing principal aquifers 62)

percent yield from five to 20 gpm, and 25 percent yield from 20 to 100 gpm. [64]

Carbonate Rocks -

The rocks mapped in this hydrogeologic unit are not all carbonates but include some shales and sandstones. The carbonates are the principal water-yielding units, and occur as both limestone and dolomite which have been deformed to varying degrees. They appear as the upper bedrock unit primarily in three northeast-southwest trending bands, two in the southeastern region enclosing a wedge of Triassic rocks and one in the central region surrounded by Silurian clastics.

Wells tapping the southeasternmost carbonate band in the Chester Valley have variable yields, often as high as 2,000 gpm where solution channels are tapped. [65] The Schuylkill River Basin is traversed by both the Great Valley and Chester Valley. The valleys mark the outcrop of the two southeastern carbonate bands; median yields of wells tapping various carbonate units in the Schuylkill River Basin range from nine to 220 gpm. [66] Farther west in the Great Valley near Harrisburg, it is reported that 1,000 gpm wells have been developed in the carbonate rocks. [67]

Middle Paleozoic Clastic Rocks -

In the central and northeastern sections of Pennsylvania, the upper bedrock surface is composed of shales, sandstones, and limestones deformed during the mountain-building period which produced the Appalachians. In some areas, these rocks are flat lying to gently dipping, but elsewhere they are extremely deformed. The sandstones are usually ridge forming, while the shales and limestones underlie valley floors. Most of the rocks were deposited during Silurian and Devonian time except for some clastics which had been deposited during later Ordovician time.

Yields of wells finished in the clastic rocks are generally moderate, but yields locally depend on geology and structure. The higher yields from wells in clastics as compared to crystalline rocks may be attributable to intergranular porosity of the sandstones and a tendency for fractures to continue to greater depths. Median yields from wells finished in various clastic units in the upper Schuylkill River Basin are reported to range from 54 to 175 gpm. [66]

Late Paleozoic Sedimentary Rocks and Coal -

Occurring in the western part of Pennsylvania, flat lying to gently dipping beds of sandstone, shale, limestone, and coal form a broad plateau with incised stream valleys. Sandstone is the best water-yielding formation; the limestone is commonly very thin.

Well yields of up to 300 gpm have been reported in certain sandstone formations.[68] Many wells have reported yields of greater than 50 gpm and a mean yield of 50 to 75 gpm is indicated.[64,4] Little information is available on depths of wells in the western area. Generally, wells are shallow because highly mineralized ground water occurs at depth.

Triassic Sedimentary Rocks -

Separating the two areas of crystalline and carbonate rocks in the southeastern region is a strip of rocks, mainly sandstones and shales with minor conglomerate, limestone, coal and intrusive diabase, varying from five to 25 miles in width. Of Triassic age, these rocks trend northeast to southwest and beyond the borders of Pennsylvania into Maryland and New Jersey. Physiographically, this section is the Triassic Lowland. The three major Triassic rock units are Stockton sandstone, Lockatong argillite and Brunswick shale. Range of yields for wells finished in the Stockton sandstone has been reported to be from 100 to 300 gpm in Chester County, although the upper one-third of the unit is not particularly productive.[65] In the Landsdale area, 120 wells in the Brunswick shale have a reported range in yield of from 10 to 350 gpm, with a median yield of 70 gpm.[69] Except in fault zones as in Chester County north of Philadelphia, yields of wells finished in the Lockatong average 10 gpm. Where faults are penetrated, yields of 100 gpm may be attained.[65]

Unconsolidated Deposits -

The two most prolific aquifers in Pennsylvania are the unconsolidated watercourse and Coastal Plain deposits. Watercourse deposits are commonly found in all the major stream valleys. They may consist of sand and gravel eroded by streams flowing off the uplands. Where a major stream had its headwaters in the glaciated region (most of the northeastern and northwestern areas of Pennsylvania as seen in Figure 2, glacial drift and meltwater-borne sediment provided additional material. Some watercourse deposits which formed before Pleistocene glaciation were buried by glacial drift; others which formed during the glacial period were buried by finer sediments (silt and clay) during the late glacial and post-glacial periods when streams could not competently carry a coarse sediment load. These buried valley deposits are often as valuable as aquifers as are sand and gravel still in contact with a stream.

In the southwestern region, selected wells are reported to yield 200 to 600 gpm. [68] In Clinton County (south-central region) several wells yield about 150 gpm. [70] In the northwest, the maximum reported yield from a sand and gravel well was 183 gpm. [71]

Watercourse deposits have been most extensively developed in the southwestern region in Allegheny and Beaver Counties. Of 147 wells in the Pittsburgh area, 101 wells have reported yields of greater than 100 gpm, with 17 greater than 500 gpm. [72] Forty-six selected wells in the Ohio River Valley in Beaver County have a mean yield of 544 gpm and a mean specific capacity of 48.3 gpm/foot of drawdown.

The Coastal Plain deposits are found in only a small area in southeasternmost Pennsylvania, near Philadelphia. These deposits consist of gently southeast dipping non-marine Cretaceous units overlain by Pleistocene marine terrace deposits. The two deepest sand and gravel units are the Farrington and Sayreville sand members of the Raritan formation which are artesian aquifers. The shallowest (Old Bridge sand) member of the Raritan formation and the Pleistocene terrace deposits are water-table aquifers. [73]

In Philadelphia, the Farrington sand is the principal aquifer, and well yields commonly are 700 to 1,100 gpm; northeast of Philadelphia in southeastern Bucks County, the Sayreville sand is the most prolific aquifer in the area although it is not often used (yields commonly 300 to 700 gpm). Water-table wells in southeastern Bucks County in sand and gravel commonly yield about 400 gpm. [73] A summary of selected wells in southeastern Bucks County indicates that 41 wells had an average yield of 320 gpm and a maximum of 1,050 gpm. [74]

Rhode Island

Except for Block Island, which lies to the south and is in the Coastal Plain, all of Rhode Island lies within the Glaciated Appalachians region. Crystalline rocks are prominent in the eastern and western parts of the state, separated by a sequence of sedimentary rocks trending north to south. Mantling these consolidated rocks nearly completely are unconsolidated deposits, primarily unstratified, unsorted glacial till but with important areas of sorted sand and gravel. Figure 16 is a generalized geologic map showing locations of the principal aquifers.

Crystalline Rocks -

The crystalline rocks of Rhode Island are found in the western half and in the southeast corner of the state. The rocks are quite variable in type and age. Metamorphic rocks include schist, gneiss, quartzite, marble, and greenstone, and igneous rocks include granite, diorite, gabbro and volcanics. 75) The ages of these rocks vary from Precambrian(?) to post-Pennsylvanian. From a water-yielding standpoint, little distinction has been made between crystalline types.

Crystalline rocks are generally tapped for domestic supplies, and yields are usually small. For 369 wells reported, the range in yield is from less than one to 96 gpm with an average of 12 gpm. Sixty percent of these wells yielded less than 11 gpm. 76)

Sedimentary Rocks -

The upper bedrock in about one-third of Rhode Island is composed of sedimentary rocks of Pennsylvanian(?) age. These rocks occur in three structural basins, the Narragansett, the North Scituate, and the Woonsocket. The rocks are predominantly non-marine clastics, ranging in composition from conglomerate to shale. Coal beds occasionally occur in the sequence. These rocks have been slightly to extensively deformed and metamorphosed.

The sedimentary rocks have a higher water-yielding capability than the crystallines. Reported yields for 418 wells range from less than one to 500 gpm with an average of 31 gpm. Fifty-two percent of the wells yield less than 11 gpm. 76)

Till -

Till mantles the bedrock nearly completely in all areas not covered by sand and gravel. In the upland areas, till is the exclusive bedrock cover. Wells finished in till generally yield less than two gpm. 76)

Sand and Gravel -

The aquifer in Rhode Island which can produce the highest yields to individual wells is composed of sand and gravel.

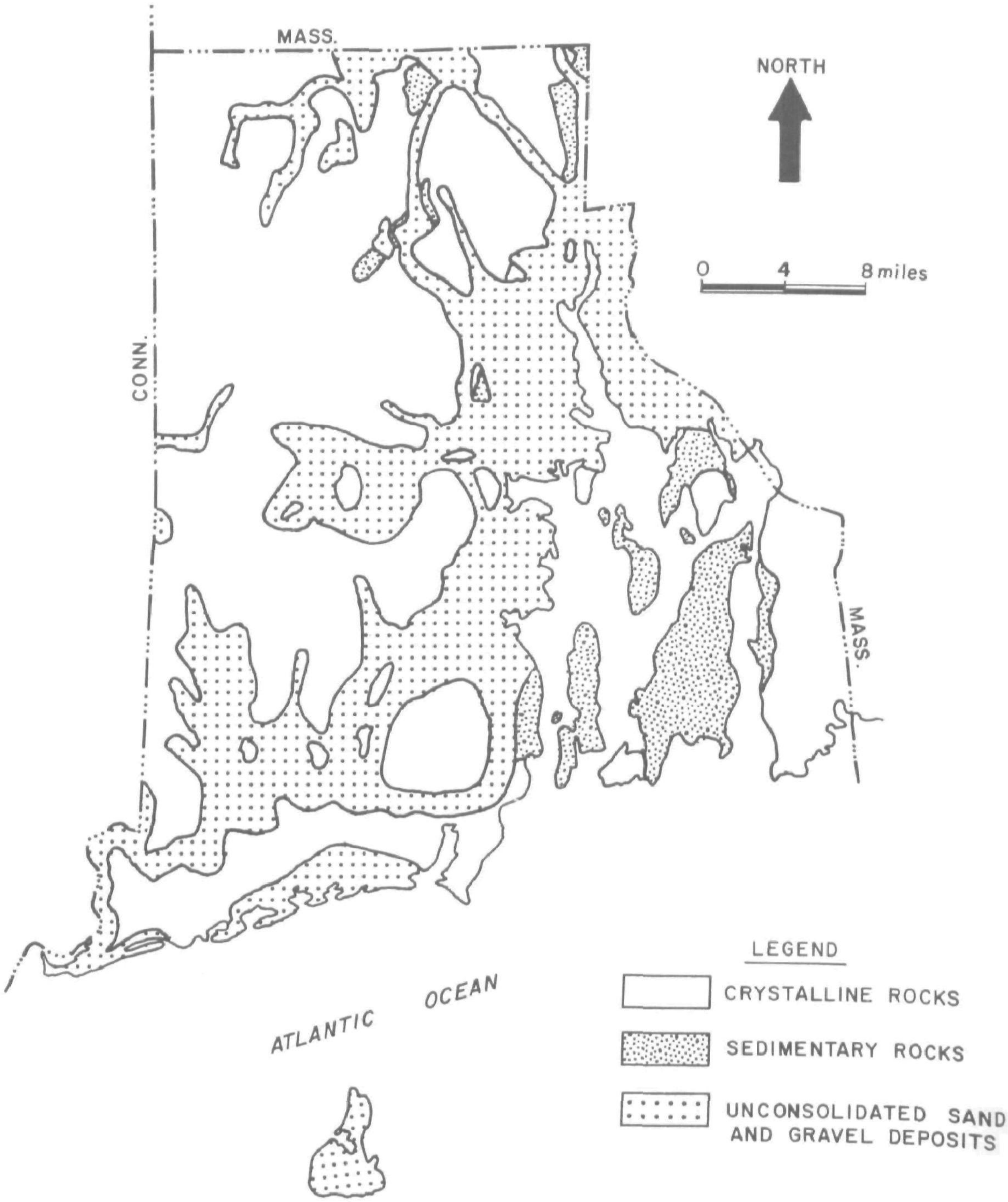

Figure 16. Generalized geologic map of Rhode Island showing principal aquifers 75,76)

These deposits are sorted and stratified, primarily composed of outwash but with associated alluvium and ice-contact units. They lie along nearly all the major streams, and especially in the central and southwestern portions, also occur in some interstream areas. [4]

Properly constructed and developed sand and gravel wells may be capable of high yields. For wells ending in outwash, one report noted a range in yield from three to 2,700 gpm. [76] For 21 public and industrial supply wells in outwash in the Providence area where the aquifer is extensive, a range of from 75 to 1,600 gpm is reported with a median yield of 425 gpm. [77]

On Block Island, yields of 11 wells believed to penetrate the Upper Cretaceous sediments range from five to 15 gpm, with a median of 12 gpm; yields from wells penetrating glacial deposits range from four to 65 gpm, with a median of 10 gpm. [78]

Vermont

In Vermont, three major consolidated rock aquifers are found; the Cambro-Ordovician carbonates of the Vermont Lowland; the Precambrian and early Paleozoic sedimentary clastics and metasediments of the Green and Taconic Mountains; and the Paleozoic crystalline rocks of the Vermont Piedmont. Unconsolidated aquifers consisting of sand and gravel are found in major stream valleys. Figure 17 is a generalized geologic map showing the principal aquifers.

Consolidated Rocks -

The Vermont Lowland located in the western portion of the state is a sequence of carbonates, quartzites, shales and slates in which carbonates dominate. [80] The carbonates are generally the principal water producer. Data on the yields and depths of wells are scanty. Reported yields of ten wells range from one to 100 gpm. [81,82,83]

Lying east of the Vermont Lowland is a highland area composed of a sequence of deformed clastic rocks metamorphosed to varying degrees. The highlands are called the Green Mountains, consisting of Precambrian and early Paleozoic argillaceous slate, schist, gneiss, phyllite, quartzite, and marble. In the southwest part of the state, a mass of similar rocks lie distinct from the Green Mountains, separated from them by the Vermont Valley. This mass forms the Taconic Mountains.

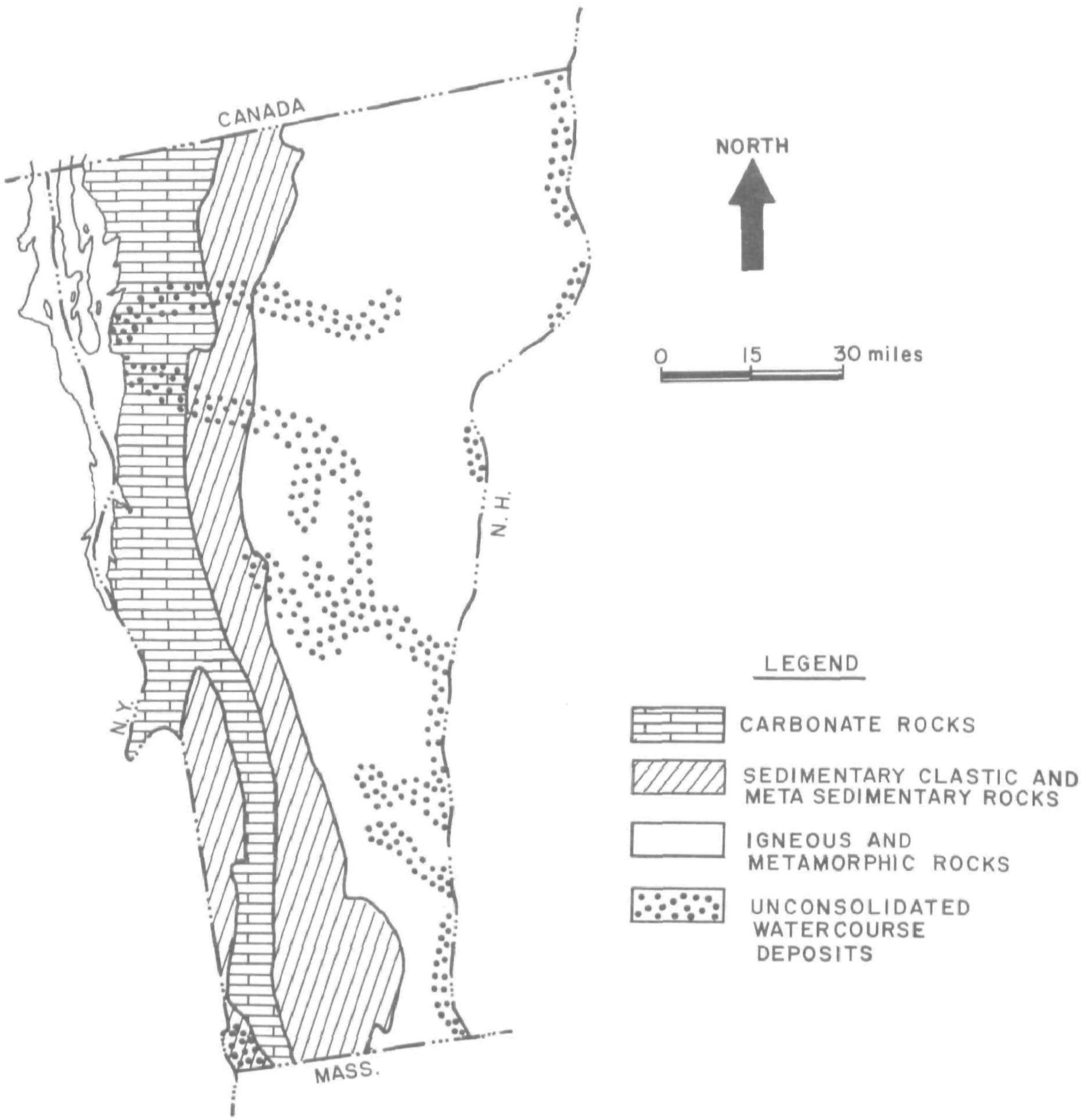

Figure 17. Generalized geologic map of Vermont showing principal aquifers [27,79]

Data on wells penetrating the Green and Taconic Mountain sequences are limited. In the Hoosic and Walloomsac River Basins of extreme southwest Vermont, four wells had a range of from four to 25 gpm with a median of seven gpm. In the West-Deerfield River Basin due east of the Hoosic River Basin, five wells penetrating bedrock range in yield from four to 100 gpm, but the median is only four gpm. [84)]

The rocks of the Piedmont of eastern Vermont are similar to those of the Green Mountains with two notable exceptions -- the Piedmont has prominent carbonates and acidic intrusives. Physiographically, the Piedmont has a gently rolling, dissected surface and is separated from the Green Mountains by a series of north-south trending valleys. Because of greater frequency of occurrences of carbonates in the Vermont Piedmont as compared to the Green Mountains, yields tend to be higher. Yields of 30 bedrock wells in five eastern Vermont river basins range from one to 100 gpm with median yields of from three to 16 gpm. [84 through 88)]

Unconsolidated Deposits -

The sand and gravel aquifer in Vermont occurs in major stream valleys. Variations in yields of wells very often depend upon the quantity of water desired. Data from selected wells in 11 major river basins were compiled by A. L. Hodges and D. Butterfield and are presented in Table 10.

Table 10. RANGE IN AND MEDIAN YIELDS OF SELECTED WELLS IN SAND AND GRAVEL AQUIFERS IN VERMONT. 81 through 91)

River basin	Number of wells	Range (gpm)	Median (gpm)
Batten Kill, Waloomsac and Hoosic	8	12 - 250	175
Otter Creek	18	6 - 450	95
Winooski	13	5 - 600	100
LaMoille	6	20 - 560	155
Missisquoi	5	20 - 600	60
West Deerfield	12	6 - 465	35
Ottanquechee-Saxton	25	7 - 1,140	40
White	18	5 - 250	43
Wells-Ompomanoosuc	10	3 - 1,100	68
Nulhegan-Passumpsic	4	60 - 800	350
Lake Memphremagog	3	50 - 550	350

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SECTION V

NATURAL GROUND-WATER QUALITY

INTRODUCTION

The natural quality of ground water is not considered by users in the region to be a problem unless the recommended limits for chemical concentrations of selected constituents as set by the states for potable public water supplies are exceeded. For the most part, the allowable chemical limits for the 11 northeast states are similar to those of the U.S. Public Health Service. [1)] Ground water which contains constituents exceeding state health department or U. S. Public Health Service recommended limits of chemical concentrations occur to some extent throughout the study area. Although it is recognized that certain industrial processes require extremely polished water, these are the exceptions, and ground water found in the northeast is suitable in quality for most purposes with little or no treatment.

Other than the natural occurrence of saline waters in aquifers and pollutants resulting from man's activities, the chemicals found in ground water result from the interaction of water with rock materials. Natural ground-water quality is intimately related to the solubility of the minerals in the rocks through which the water moves. The chemical character of ground water can be associated with a particular rock type. Where the rocks are similar in mineralogy over broad areas, the chemical character of the water is generally consistent. Where localized occurrences of soluble, atypical mineral suites are present, the chemical quality of local ground water reflects these minerals.

Since ground water is not static, but constantly in motion, there often is a change in quality as water moves within the aquifer, and from one rock type to another. The capability of an aquifer to circulate water has a distinct influence on the mineral content. In the highly permeable but areally-limited glacial aquifers, circulation is rapid and water quality is generally good. In some Coastal Plain deposits, water can migrate many miles from the intake area to the discharge area, and generally increases in mineral content due to the very long travel time associated with such a migration. Changes in relative composition may also occur, such as the softening that takes place during movement through greensands.

Consolidated rock aquifers are extremely variable in their circulation capability. Generally, these aquifers have only limited circulation below depths of 500 feet. Below this depth, water can be highly mineralized, with high chloride and total dissolved solids the primary objectionable constituents. Figure 18 is a map of the 11-state study area showing the depth to mineralized ground water in the major aquifers. Fortunately, saline-water aquifers are normally overlain by fresh-water aquifers. Although the remaining portion of the region is shown to be less than 1,000 mg/l, (milligrams per litre), there may be some localized areas where mineralized water occurs at depth. However, because there is no need to drill deep wells for fresh-water supplies at these locations, little or no information is available on the quality of water below the fresh-water zones.

By far the most widespread problem in the northeast region is the naturally high iron content of ground water (often associated with a high concentration of manganese), low pH, and sometimes high hardness. This problem is not confined to any region or aquifer type, but occurs in the three major water-yielding units: the unconsolidated deposits of the Coastal Plain, the unconsolidated glacial deposits, and the consolidated rocks.

Individual domestic wells, even when they yield water high in iron content, rarely are equipped with treatment facilities. However, many municipal and industrial supplies must be treated for iron and manganese, or the pH must be adjusted and the hardness reduced. Some supplies must be treated for more than one of the above parameters.

Following is a state-by-state discussion of natural water quality. Tables have been prepared for each state, and they present information on natural water quality in the principal aquifers. In some cases it was not possible from the reported data to determine whether the occurrence of high concentrations of certain mineral constituents in specific wells is actually natural or has been caused by man's activities. Therefore, median values have been computed and are probably the most representative of natural water quality conditions.

CONNECTICUT

The natural quality of the ground water in Connecticut is extremely variable among aquifers and within relatively short distances in the same aquifer. The concentrations of many constituents have wide ranges which may impose some constraints on the industrial utilization of water, especially where extremely high-quality process water is required.

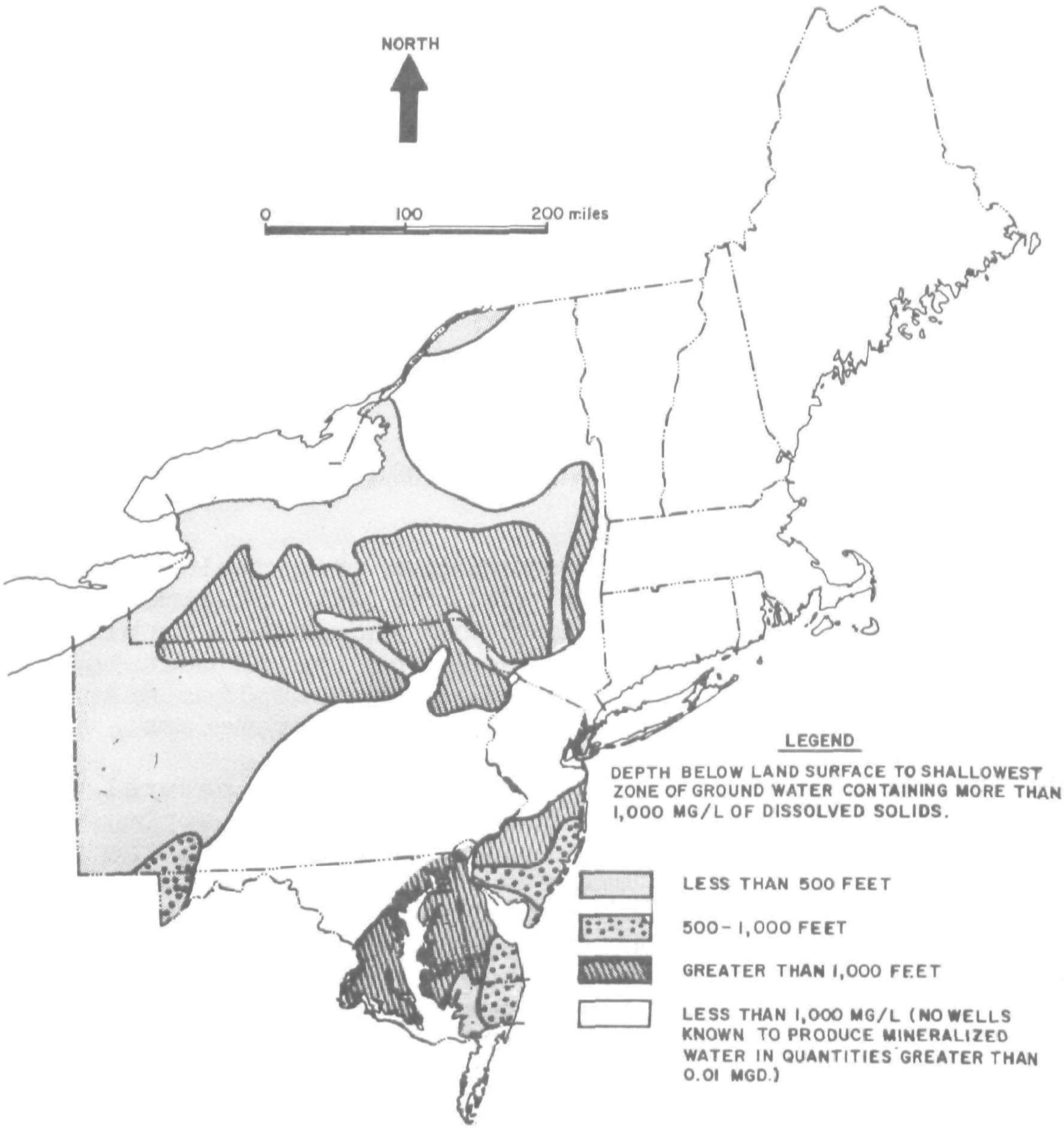

Figure 18. Depth to mineralized ground water in major aquifers in the northeast United States [2)]

Table 11 is the compilation of chemical analyses from the various aquifers, taken from several published sources including regional and river basin reports. A wide range of concentrations exists throughout the regions of the state for almost all of the constituents. Many of the upper values far exceed recommended limits of drinking water standards. However, where more than three analyses are tabulated, only rarely does the median value exceed these limits. The median manganese value of six analyses in the south-central sand and gravel deposits is above the recommended limit. Based on analyses of 96 water samples from wells tapping the crystalline rocks in the southeastern coastal region of Connecticut, 27 percent contained iron concentrations equal to or exceeding the State Health Department limits. Of 89 well samples, 31 percent contained objectionable manganese concentrations. Approximately 50 to 75 percent of the wells tapping the bedrock (schist) in eastern Connecticut yield water that would require treatment for iron and manganese. 4)

Naturally-occurring salt water in aquifers along the coast and estuaries has not been studied in great detail. However, it is known to be present in some areas of the coastal region and also in areas several miles inland along estuaries, particularly in less permeable unconsolidated deposits where flushing by fresh water has been incomplete.

The occurrence of high concentrations of sulfate has been noted in some ground-water supplies, generally limited to the sedimentary rocks of the central portion of the state. However, only two public-supply systems using ground water have average concentrations exceeding the state standard.

The average concentrations of chemical constituents over a five year period (1966 through 1970) from all the individual sources for public supply indicate that the water is of good quality. Table 12 lists the maximum concentrations of selected constituents for drinking water allowed by the state and the number of public supply wells and springs where the average concentration over a five-year period was equal to or exceeded the limits. As can be seen, the major natural water-quality problem is iron concentration. It should be noted that many of the excessive concentrations, particularly iron, manganese, color, and turbidity, were found in the same water sources. The natural chloride content found in water throughout the state is low, rarely exceeding 20 mg/l, except in some locales along coastal areas and estuaries.

DELAWARE

The natural ground water of Delaware is generally of suitable

Table 11. CHEMICAL ANALYSES OF GROUND WATER IN CONNECTICUT. (Concentrations in milligrams per liter.) 3 through 13)

		Iron (Fe)			Manganese (Mn)			Sulfate (SO_4)		
Location	Rock Type	N	Range	M	N	Range	M	N	Range	M
Northeast	X	104	0.00 - 4.8	0.07	105	0.00 - 0.94	0.00	68	2.4 - 39	13
	S/G	34	0.00 - 2.8	0.06	33	0.00 - 5.7	0.01	34	0.2 - 37	12
	T	14	0.00 - 0.49	0.09	12	0.00 - 0.10	0.00	12	6.9 - 26	13
Southeast	X	98	0.00 - 8.2	0.10	91	0.00 - 0.94	0.02	44	1.6 - 1,040	17
	S/G	51	0.01 - 2.3	0.10	49	0.00 - 0.78	0.02	38	1.2 - 109	17
	T	7	0.02 - 8.1	0.14	7	0.00 - 0.27	0.01	2	30 - 41	-
North Central	X	20	0.02 - 3.6	0.28	19	0.00 - 0.25	0.03	20	6.4 - 39	14
	Tr	35	0.00 - 1.5	0.15	15	0.00 - 0.12	0.01	28	3 - 1,500	27
	S/G	79	0.01 - 0.32	0.10	68	0.00 - 9.9	0.03	64	2.3 - 292	26
	T	2	0.84 - 2.0	-	2	0.02 - 0.08	-	2	7.2 - 21	-
South Central	X	3	0.02 - 0.20	-	3	0.03 - 0.20	-	4	7.1 - 22	-
	Tr	5	0.01 - 0.19	0.10	5	0.02 - 0.18	0.04	5	9.1 - 35	29
	S/G	6	0.02 - 0.16	0.06	6	0.02 - 0.29	0.11	9	15 - 83	27
	T	2	0.03 - 0.19	-	2	0.07 - 0.22	-	3	12 - 16	-
Northwest	X	76	0.00 - 1.0	0.09	76	0.00 - 0.65	0.02	76	3.2 - 178	19
	C	27	0.00 - 3.4	0.06	27	0.00 - 0.23	0.01	27	8 - 74	23
	S/G	29	0.00 - 2.1	0.06	29	0.00 - 0.59	0.04	29	7.2 - 178	23
Southwest	X	58	0.01 - 8.6	0.14	58	0.00 - 0.66	0.03	58	8.9 - 72	20
	S/G	18	0.01 - 0.84	0.06	18	0.00 - 0.24	0.03	18	12 - 39	19
	T	3	0.04 - 0.48	-	3	0.01 - 0.17	-	3	52 - 274	-

X - Crystalline rocks
T - Till
S/G - Sand and gravel
Tr - Sedimentary rocks
C - Carbonate rocks

N - Number of samples
M - Median

Table 11 (continued). CHEMICAL ANALYSES OF GROUND WATER IN CONNECTICUT.
(Concentrations in milligrams per liter.) 3 through 13)

Location	Rock Type	Chloride (Cl) N	Chloride (Cl) Range	Chloride (Cl) M	Nitrate (NO_3) N	Nitrate (NO_3) Range	Nitrate (NO_3) M
Northeast	X	27	2.0 - 70	6.5	100	0 - 60	0.9
	S/G	15	2.8 - 84	7.1	30	0 - 44	2.9
	T	2	3.2 - 14	-	12	0.3 - 26	8.3
Southeast	X	51	0 - 362	13	22	0.1 - 32	3.7
	S/G	58	4.0 - 607	17	18	0.3 - 43	3.2
	T	5	5.3 - 16	9.0	4	0 - 52	-
North Central	X	22	0.4 - 10	2.7	22	0 - 24	0.45
	Tr	54	0.6 - 1,029	5.3	45	0 - 20	0.71
	S/G	82	0 - 48	4.6	79	0 - 86	5.7
	T	2	1.5 - 3.5	-	2	0.5	-
South Central	X	4	1.5 - 3.0	-	-	-	-
	Tr	5	3.0 - 22	9.0	-	-	-
	S/G	9	3.2 - 70	9.5	1	60	-
	T	3	1.5 - 3.6	-	-	-	-
Northwest	X	76	0.8 - 78	5.4	76	0 - 39	0.6
	C	27	0.9 - 72	8.0	27	0 - 16	4.6
	S/G	29	0.3 - 92	8.0	29	0 - 25	1.0
Southwest	X	58	2.6 - 140	9.6	58	0 - 40	0.3
	S/G	18	2.0 - 37	12	21	0 - 34	2.2
	T	3	350 - 1,700	-	3	0 - 1.4	-

Table 11 (continued). CHEMICAL ANALYSES OF GROUND WATER IN CONNECTICUT. (Concentrations in milligrams per liter.) 3 through 13)

Location	Rock Type	Total Dissolved Solids N	Total Dissolved Solids Range	Total Dissolved Solids M	Total Hardness (as $CaCO_3$) N	Total Hardness (as $CaCO_3$) Range	Total Hardness (as $CaCO_3$) M	pH N	pH Range	pH M
Northeast	X	97	24 - 409	100	100	7 - 279	54	104	5.1 - 8.6	7.0
	S/G	34	31 - 330	80	35	9 - 108	37	35	4.8 - 9.3	6.5
	T	13	79 - 434	108	12	38 - 211	50	14	5.8 - 7.7	6.6
Southeast	X	97	24 - 1,830	118	97	3 - 1,120	57	97	4.4 - 8.1	7.2
	S/G	51	36 - 1,270	96	51	2 - 296	42	51	5.8 - 7.7	6.9
	T	8	40 - 678	82	8	22 - 100	36	8	5.0 - 7.3	7.0
North Central	X	21	42 - 184	111	22	21 - 132	61	22	6.3 - 8.2	7.1
	Tr	42	43 - 2,510	161	52	14 - 2,500	110	42	5.7 - 8.9	7.4
	S/G	73	30 - 821	132	78	6 - 486	64	80	5.0 - 8.3	6.8
	T	2	44 - 58	-	2	22 - 26	-	2	6.1 - 6.5	-
South Central	X	3	39 - 145	-	4	20 - 111	-	4	6.3 - 7.4	-
	Tr	5	89 - 212	157	5	28 - 143	83	5	6.5 - 8.7	7.7
	S/G	6	86 - 233	131	9	40 - 266	103	8	6.4 - 7.8	6.8
	T	2	56 - 67	-	3	30 - 40	-	3	6.4 - 6.9	-
Northwest	X	76	34 - 404	136	76	15 - 264	85	76	6.4 - 7.9	7.4
	C	27	84 - 496	275	27	76 - 378	230	27	7.1 - 8.1	7.7
	S/G	29	60 - 513	237	29	36 - 365	190	29	6.7 - 8.1	7.7
Southwest	X	58	52 - 354	124	58	30 - 266	73	58	5.7 - 8.2	7.5
	S/G	18	71 - 225	112	18	21 - 188	53	18	6.4 - 7.7	6.9
	T	3	718 - 3,300	-	3	99 - 777	-	3	6.9 - 7.1	-

Table 12. NUMBER OF GROUND-WATER SOURCES USED FOR PUBLIC SUPPLY EQUAL TO OR EXCEEDING STATE OF CONNECTICUT DRINKING WATER STANDARDS FOR SELECTED CONSTITUENTS. [14)]

Constituent	Maximum concentrations allowed	Number of public water-supply sources yielding ground water equal to or exceeding standard
Chloride (Cl)	250 a)	3
Total Hardness (as $CaCO_3$)	150 a)	86
Iron (Fe)	0.3 a)	115
Manganese (Mn)	0.05 a)	85
Sodium (Na)	20 a)	71
Sulfate (SO_4)	250 a)	2
Fluoride (F)	1.2	6
Turbidity	5 units	43
Color (true)	15 units	10

a) These limits should not be exceeded if better quality water can be made available.

quality for most purposes, with only minor treatment required in isolated instances. Table 13 is a compilation of chemical analyses of selected constituents in natural ground waters. Usually the water from the shallow zones is of better quality than that obtained from the deep zones. Little is known about the quality of water at depths of 1,000 feet or greater, but it is inferred that these waters would be high in dissolved solids.

There is little information available on the water quality in the Unglaciated Appalachians. Waters from the carbonate rocks have a higher hardness than from the other crystalline rock types. Normally, the calcium and magnesium content is higher in water from the basic crystalline rocks, such as gabbro, than from the acidic rocks. Occasionally, high iron content is encountered locally in concentrations that may require treatment.

The natural water quality of the Coastal Plain deposits is good and, with the exception of spotty high iron content, little or no treatment is required for most purposes. Brackish or salty water can be found in portions of nearly all of the aquifers. The locations of the salt-water interface have been fairly well documented and mapped.

The ground water from Quaternary age aquifers is characteristically slightly acidic, with a pH of around 6. The iron content is often troublesome, requiring some form of treatment. The water is usually soft, and contains low concentrations of total dissolved solids.[15)]

The Tertiary sediments of Miocene age yield water with a pH above 7 and low dissolved iron content. The bicarbonate and silicate concentrations are higher than other aquifers in the region. The underlying deposits of Eocene and Paleocene age have water with a wide range of pH values, and occasionally high iron content. Moderately high dissolved solids and hardness are found.

The Upper Cretaceous marine sediments are not extensively tapped in the state. Few chemical analyses of the water are available, but indications are that the quality is very good. Chemical analyses of water from the Magothy formation show both basic and acidic pH values. The basic waters are typically found at depth and downdip. Total iron and sulfate concentrations are relatively high. Water from the Lower Cretaceous basal unit is similar to the Magothy formation.

Table 13. CHEMICAL ANALYSES OF GROUND WATER IN DELAWARE. (Concentrations in milligrams per liter.) 15 through 23)

Location - Age	Rock Type	Iron (Fe) N	Iron (Fe) Range	Iron (Fe) M	Manganese (Mn) N	Manganese (Mn) Range	Manganese (Mn) M	Sulfate (SO_4) N	Sulfate (SO_4) Range	Sulfate (SO_4) M
Piedmont Province										
Precambrian	X	9	0.04 - 1.2	0.99	-	-	-	12	1.9 - 84	32
Coastal Plain										
Cretaceous	Nm	68	0 - 11	1.35	32	0 - 0.2	0.1	52	0 - 141	5.4
	Mt	4	0.25 - 6.3	-	-	-	-	6	4.2 - 23	10.4
	Ma	9	0.08 - 0.69	0.17	-	-	-	8	4.6 - 84	22
Tertiary	Pe	2	0.25 - 3.9	-	-	-	-	-	-	-
	Mio	16	0 - 42.5	0.15	-	-	-	27	0 - 17	4.9
Quaternary	Pl	117	0 - 123	0.3	7	0 - 0.5	0	113	0 - 82	7

X - Crystalline rocks
Nm - Non-marine sediments
Mt - *Magothy aquifer (transitional sediments)*
Ma - Marine sediments
Pe - Paleocene and Eocene sediments
Mio - Miocene sediments
Pl - Pleistocene sediments

N - Number of samples
M - Median

Table 13 (continued). CHEMICAL ANALYSES OF GROUND WATER IN DELAWARE. (Concentrations in milligrams per liter.) 15 through 23)

Location - Age	Rock Type	Total Dissolved Solids N	Total Dissolved Solids Range	Total Dissolved Solids M	Total Hardness (as $CaCO_3$) N	Total Hardness (as $CaCO_3$) Range	Total Hardness (as $CaCO_3$) M	pH N	pH Range	pH M
Piedmont Province										
Precambrian	X	3	35 - 353	-	11	32 - 158	60	17	5.0 - 7.4	6.3
Coastal Plain										
Cretaceous	Nm	23	33 - 350	86	75	5 - 245	34	87	5.4 - 7.6	6.6
	Mt	4	50 - 64	-	8	18 - 44	23	8	5.9 - 7.2	6.7
	Ma	1	152	-	9	6 - 162	87	9	5.5 - 7.9	6.2
Tertiary	Pe	-	100 - 1,000	-	-	15 - 200	-	-	5.6 - 8.6	-
	Mio	10	177 - 248	208	31	6.6 - 1,500	101	30	4.9 - 8.3	6.6
Quaternary	Pl	20	34 - 1,280	84	149	1.7 - 2,320	32	107	3.4 - 7.5	6.2

Location - Age	Rock Type	Chloride (Cl) N	Chloride (Cl) Range	Chloride (Cl) M	Nitrate (NO_3) N	Nitrate (NO_3) Range	Nitrate (NO_3) M
Piedmont Province							
Precambrian	X	14	5.5 - 550	9.3	4	7.6 - 20	-
Coastal Plain							
Cretaceous	Nm	88	1.5 - 218	6.5	33	0 - 24	0.6
	Mt	9	1.5 - 16	3.0	6	0 - .6	0.3
	Ma	9	3.5 - 82	28	8	0.2 - 68	37
Tertiary	Pe	-	1 - 200	-	-	0 .1 - 30	-
	Mio	31	1.5 - 4,000	11	20	0 - 29	0.1
Quaternary	Pl	100	4 - 6,300	13	96	0 - 120	9.25

MAINE

Except for the common problems caused by high iron and manganese, and high hardness of water from carbonate rocks, Maine has natural ground water of excellent quality. However, it does have local water-quality problems that are unusual. Table 14 is a compilation of chemical analyses of selected constituents in natural ground waters.

In two areas of the state, one in the Central Uplands and one in the Coastal Lowlands, the ground water shows levels of radioactivity considerably higher than usual. The source of this activity is believed to be radioactive minerals present in the pegmatites found in these areas.

In the Coastal Lowlands, it is not uncommon for a well to produce water with high total dissolved solids and chloride concentrations. Sea water entered aquifers in the coastal area when they were submerged between periods of Pleistocene glaciation. Many of these aquifers have not been completely flushed by circulating fresh ground water since that time.

MARYLAND

Natural ground water in Maryland is generally of good quality, with exceptions in localized areas. Table 15 is a compilation of chemical analyses of selected constituents in natural ground waters.

Although saline waters can be found in the deeper Coastal Plain formations, the overlying aquifers contain an abundance of fresh water which is available for development for most purposes with little or no treatment required. Generally, mineralized water can be found below depths of 500 feet in the consolidated rock aquifers.

In the consolidated rock aquifers west of the Fall Line, the water quality is greatly dependent on the chemical nature of the aquifer material. For example, the water from the crystalline rocks is usually softer and has a lower pH than water obtained from the carbonate rocks. Although a wide range of dissolved solids is found in water from wells tapping the crystallines, the highest concentrations are in waters from the carbonates. High iron concentrations of water from both types of rocks are fairly localized problems. Not much data are available on the natural water quality of the aquifers in the sedimentary rocks in the western portion of the state. In many places saline water can be found below a depth of 500 feet, although some deeper wells reportedly yield potable water supplies.

Table 14. CHEMICAL ANALYSES OF GROUND WATER IN MAINE. (Concentrations in milligrams per liter.) 24 through 30)

Rock Type	Iron (Fe)			Chloride (Cl)			Total Hardness (as $CaCO_3$)		
	N	Range	M	N	Range	M	N	Range	M
C	19	0 - 1.3	0.02	19	2.2 - 36	11	16	20 - 281	197
U	17	0 - 1.5	0.05	26	0.2 - 22	6.1	13	5 - 225	61

Rock Type	Total Dissolved Solids			pH		
	N	Range	M	N	Range	M
C	14	41 - 355	153	17	6.6 - 8.1	7.3
U	20	2 - 230	58	19	5.7 - 8.4	6.9

C - Consolidated rock
U - Unconsolidated deposits
N - Number of samples
M - Median

Table 15. CHEMICAL ANALYSES OF GROUND WATER IN MARYLAND. (Concentrations in milligrams per liter.)
31 through 36)

Location	Rock Type	Iron (Fe) N	Iron (Fe) Range	Iron (Fe) M	Chloride (Cl) N	Chloride (Cl) Range	Chloride (Cl) M	Total Hardness (as $CaCO_3$) N	Total Hardness (as $CaCO_3$) Range	Total Hardness (as $CaCO_3$) M
Central Maryland	X	53	0 - 4.6	0.16	52	0.1 - 26	4.8	54	7 - 246	40
Central Maryland	C_s	7	0 - 1.2	0.09	7	2.1 - 64	5.8	7	93 - 198	130
Coastal Plain	U	105	0 - 15	0.20	123	0.2 - 1,830	7.1	110	2.0 - 615	60

Location	Rock Type	Total Dissolved Solids N	Total Dissolved Solids Range	Total Dissolved Solids M	pH N	pH Range	pH M
Central Maryland	X	46	13 - 321	73	54	5.4 - 8.3	6.7
Central Maryland	C_s	7	128 - 274	182	7	6 - 8.1	7.7
Coastal Plain	U	113	12 - 698	84	207	3.8 - 8.7	6.5

X - Precambrian crystalline rocks
C_s - Carbonate rocks and shale
U - Unconsolidated deposits
N - Number of samples
M - Median

It is difficult to generalize on the water quality of the extensive Coastal Plain aquifers. Water quality is known to change as ground water migrates from the recharge to the discharge areas, and inter-aquifer transfers of water may have a considerable effect on concentrations of chemical constituents. The occurrence of saline water is generally at shallower depth in an easterly direction. Although some local conditions modify the situation, the inland third of this province contains the deepest fresh-water aquifers, possibly to depths of 2,000 feet. The central section contains fresh water to depths of about 1,500 feet, and the eastern area aquifers are probably saline below depths of 500 feet.

The Quaternary age aquifers, because of relatively rapid ground-water circulation, contain water which is low in dissolved mineral constituents. Those areas containing calcareous shell material yield hard water. High iron content is commonly a troublesome factor.

Of the Tertiary age aquifers, water derived from the Miocene units is high in total dissolved solids and has a pH of 7 or above. The hardness is high, especially in water from formations containing a large amount of shell material. The Eocene and Paleocene aquifers yield water with a wide range of pH values. High iron concentrations are often associated with glauconitic material in these aquifers.

The Cretaceous aquifers yield water having a relatively high iron content and a wide range of pH values. The sulfate content is often high, and is thought to be derived from sulfide minerals.

MASSACHUSETTS

The quality of natural ground water in Massachusetts is generally good. However, mineralization problems do occur, frequently associated with a particular rock type. Table 16 is a compilation of chemical analyses of selected constituents in natural ground waters.

Ground water is generally soft. However, in the carbonate belt in western Massachusetts, a large percentage of wells in all of the aquifers yield water with at least moderate hardness. For 43 wells in all aquifers in the Housatonic River Basin, all but four produced at least moderately hard water. 37)

Wells in the Triassic sedimentary rocks of the Connecticut River Valley yield water high in total dissolved solids.

Table 16. CHEMICAL ANALYSES OF GROUND WATER IN MASSACHUSETTS. (Concentrations in milligrams per liter.) 37 through 50)

Location	Rock Type	Iron (Fe)			Chloride (Cl)			Sulfate (SO_4)		
		N	Range	M	N	Range	M	N	Range	M
Northeast	X	20	0.05 - 4.4	0.24	19	1.6 - 54	5.3	17	0.4 - 51	16
	S/G	88	0 - 2.4	0.08	91	2.0 - 2,400	10	47	0.2 - 89	19
	T	9	0.03 - 1.4	0.14	9	0.3 - 56	6.0	7	4.2 - 47	12
Southeast	X	8	0 - 2.0	0.10	8	4.0 - 16	10	8	1.2 - 40	13
	S/G	19	0 - 0.69	0.10	19	5.0 - 36	10	19	5.6 - 60	8.2
	T	4	0.03 - 1.1	-	4	5.9 - 13	-	4	14 - 18	-
West	X	34	0 - 6.0	0.06	37	1.0 - 37	6.0	15	0 - 48	16
	Tr	3	0.12 - 1.0	-	3	4.6 - 25	-	3	24 - 208	-
	C	17	0 - 0.27	0.04	17	0.8 - 138	6.0	17	3.8 - 28	19
	S/G	102	0 - 10.0	0.10	97	1.0 - 325	4.4	31	3.4 - 29	12
	T	8	0.01 - 0.20	0.05	9	0.5 - 28	4.8	6	8.8 - 27	14

X - Crystalline rocks
Tr - Triassic sedimentary rocks
C - Carbonate rocks
S/G - Sand and gravel
T - Till

N - Number of samples
M - Median

Table 16 (continued). CHEMICAL ANALYSES OF GROUND WATER IN MASSACHUSETTS. (Concentrations in milligrams per liter.) 37 through 50)

Location	Rock Type	Total Hardness (as $CaCO_3$)			Total Dissolved Solids			pH		
		N	Range	M	N	Range	M	N	Range	M
Northeast	X	18	17 - 150	55	17	13 - 267	99	19	6.5 - 8.1	7.3
	S/G	87	8 - 424	38	54	32 - 4,510	180	90	5.3 - 8.1	6.5
	T	7	15 - 140	43	9	25 - 444	94	9	5.7 - 7.8	6.4
Southeast	X	8	13 - 130	38	8	0.16 - 197	92	8	5.9 - 7.9	6.8
	S/G	18	9 - 70	15	19	33 - 268	62	19	5.3 - 6.8	6.0
	T	4	18 - 33	-	4	68 - 89	-	4	6.0 - 6.6	-
West	X	30	14 - 213	88	24	40 - 263	127	38	6.2 - 9.0	7.5
	Tr	3	18 - 109	-	3	90 - 468	-	3	6.3 - 7.8	-
	C	17	1 - 356	215	17	120 - 509	236	17	7.1 - 8.2	7.7
	S/G	83	10 - 259	56	28	48 - 278	144	120	5.6 - 8.2	6.5
	T	8	30 - 204	77	6	48 - 245	120	9	6.1 - 8.4	7.1

Like ground water in the carbonate belt of western Massachusetts, the ground water in this area is alkaline. High pH is usually equated with high hardness and alkalinity, but this is not the case in the Connecticut River Valley. What does occur is dissolution of sulfide and sulfate minerals in the Triassic rocks, producing ground water high in sulfates and total dissolved solids. [38,51]

In the northeastern portion of the state, where crystalline rocks form the bedrock, calcic minerals raise the pH and hardness. Of 18 wells in the lower Ipswich River Basin, nine produced water which could be classified as at least moderately hard. The wells with water of highest hardness were those in bedrock.

The most prevalent natural ground-water problem in Massachusetts is excessive concentrations of iron and manganese in ground water. This is especially common where the ground water has an acidic pH, which includes most areas of the state. [38] In the Housatonic River Basin, where the ground water is commonly alkaline, 11 wells out of 43 reportedly produced water with a pH less than 7, and four out of 43 exceeded the U. S. Public Health Service recommended limits for iron or manganese. [37] In the Deerfield River Basin, northeast of the Housatonic River Basin, in 33 analyses of the 90 for which pH was reported, the pH was less than 7; out of analyses for 87 wells for which iron or manganese concentrations were reported, 34 exceeded the U. S. Public Health Service limits. [40]

NEW HAMPSHIRE

The quality of natural ground water in New Hampshire is excellent. Table 17 is a compilation of chemical analyses of selected constituents in natural ground waters. Hardness is generally less than 60 mg/l. A hardness level of 100 mg/l is rarely exceeded. [51]

High concentrations of iron and manganese can be troublesome, particularly in sand and gravel wells, as in most of the northeast states. From the scanty data available, high iron and manganese concentrations appear to be a spotty problem, but concentrations rarely exceed 1.0 mg/l and 0.20 mg/l, respectively.

An unusual natural water-quality problem in New Hampshire is the occurrence of high fluorides, especially in wells in the Ossipee Mountains north of Lake Winnipesaukee and in the Laconia area south of the lake. At Conway, well waters are reported to commonly contain 2.5 mg/l of fluoride. In Lincoln

Table 17. CHEMICAL ANALYSES OF GROUND WATER IN SOUTHEASTERN NEW HAMPSHIRE. (Concentrations in milligrams per liter.) [52,53]

Rock Type	Iron (Fe)			Chloride (Cl)			Sulfate (SO_4)		
	N	Range	M	N	Range	M	N	Range	M
X	7	0.01 - 0.66	0.12	7	0.8 - 240	4.1	6	2.6 - 24	9.3
S/G	30	0 - 0.80	0.035	52	0.1 - 133	9.5	24	1.4 - 54	12.5
T	6	0 - 0.07	0.005	7	5.9 - 28	14	2	4 - 15	-

Rock Type	Total Hardness (as $CaCO_3$)			Total Dissolved Solids			pH		
	N	Range	M	N	Range	M	N	Range	M
X	6	32 - 95	46	6	72 - 525	93.5	7	5.9 - 8.2	7.9
S/G	35	9 - 139	43	24	36 - 191	78.5	52	5.7 - 8.3	6.8
T	3	7 - 64	-	2	33 - 134	-	4	6.4 - 7.6	-

X - Crystalline rock
S/G - Sand and gravel
T - Till
N - Number of samples
M - Median

and Waterville Valley, some wells 200 to 300 feet deep have similarly high values. East of Concord, near Bow, a large number of wells have been sampled, and there is an obvious fluoride problem. Near Wolfboro, at the southeastern end of Lake Winnipesaukee, a well serving a restaurant was reported to have a fluoride content over 10 mg/l. [54]

NEW JERSEY

In general, the quality of natural ground water in the various regions of New Jersey is good. Table 18 is a compilation of chemical analyses of selected constituents in natural ground waters.

The major aquifer in the westernmost part of the state is the Kittatinny limestone. Water from this formation is hard, in excess of 150 mg/l and up to 500 mg/l, with a pH of over 7. The younger Richenback and Epler formations locally have a moderate to high hydrogen sulfide content. The Martinsburg formation produces water with a low pH, in the range of 5 to 6. The hardness, although highly variable, is moderate -- usually less than 100 mg/l. However, in some locales hardness concentrations can be very high, with levels up to 500 mg/l. Another problem associated with water from this unit is the high hydrogen sulfide content.

The Precambrian crystalline rocks to the east contain ground water with a wide range of iron concentrations, dependent on the mineral content of the rock. Usually the pH of the water is low with only minor concentrations of hardness. High iron content is associated with water from the darker colored rocks and can be as much as 12 mg/l.

The Triassic rock aquifers are widely utilized by municipal and industrial supply wells. Water from the Stockton formation has a pH from 6 to 7, with a hardness between 100 and 200 mg/l. The iron and sulfate contents are variable, with high concentrations found in the deeper sections. Wells penetrating the Lockatong and Brunswick formations yield water with a pH greater than 7 and locally high sulfate concentrations. Hardness is highly variable, with many wells yielding water that exceeds the state drinking water recommended limits.

Ground water from the Pleistocene deposits is highly variable, particularly with regard to concentrations of iron. Most waters can be expected to have values of less than one mg/l of iron. The hardness is low to moderate with a slightly acid pH.

Table 18. CHEMICAL ANALYSES OF GROUND WATER IN NEW JERSEY. (Concentrations in milligrams per liter.) 55 through 72)

Location	Rock Type	Iron (Fe) N	Iron (Fe) Range	Iron (Fe) M	Chloride (Cl) N	Chloride (Cl) Range	Chloride (Cl) M	Total Hardness (as $CaCO_3$) N	Total Hardness (as $CaCO_3$) Range	Total Hardness (as $CaCO_3$) M
Precambrian region	X	7	0.02 - 12	0.10	18	1 - 40	6	18	13 - 157	61
Carbonate region	C	3	0.10 - 0.40	-	2	6 - 8	-	3	52 - 176	-
Triassic region	Tr	31	0 - 3.6	0.13	35	1 - 1,900	11	33	18 - 2,870	187
	Qt	13	0.03 - 3.0	0.07	25	2.1 - 27	7.5	25	32 - 375	116
Coastal Plain	K	118	0 - 114	2.5	122	1.1 - 2,057	12.5	63	4 - 580	76
	T	141	0 - 25	0.55	170	1.9 - 1,510	9.1	161	0 - 492	34
	Qc	28	0.01 - 22	0.25	34	3.1 - 160	9.7	27	4 - 182	31

Location	Rock Type	Total Dissolved Solids N	Total Dissolved Solids Range	Total Dissolved Solids M	pH N	pH Range	pH M
Precambrian region	X	18	51 - 246	118	18	5.2 - 8.1	6.8
Carbonate region	C	-	-	-	3	6.9 - 8.2	-
Triassic region	Tr	26	45 - 4,780	448	35	6.0 - 8.9	7.4
	Qt	7	134 - 230	156	25	6.1 - 8.2	7.6
Coastal Plain	K	92	27 - 543	123	102	3.9 - 8.9	6.9
	T	114	15 - 3,030	103	174	4.0 - 9.2	7.1
	Qc	18	14 - 482	51	30	4.4 - 8.1	5.8

X - Precambrian crystalline rocks
C - Paleozoic carbonate rocks
Tr - Triassic sedimentary rocks
Qt - Quaternary deposits over Triassic rocks

K - Cretaceous unconsolidated rocks
T - Tertiary unconsolidated rocks
Qc - Quaternary unconsolidated rocks

N - Number of samples
M - Median

The natural ground-water quality in the Coastal Plain is generally very good. However, not all the deep aquifers can be used for potable water supplies. Some formations contain saline water below a depth of 1,000 feet in the downdip sections.

Water from the Cretaceous age Raritan and Magothy formations occasionally has a high iron content. Dissolved solids are low and appear to increase downdip. The pH is only slightly acid. The other important aquifers of Cretaceous age, including the Englishtown, Wenonah, and Mount Laurel, contain water with low dissolved solids. Spotty occurrences of high iron content are found, particularly within the Englishtown formation.

The Tertiary age aquifers vary in water quality among the different formations and also within the same formation. The Vincentown is characterized by water which is moderately hard to hard, and the dissolved solids and iron content are occasionally very high. The Kirkwood yields soft water, with relatively minor problems associated with excessive iron concentrations. The Cohansey contains very soft water with localized high iron concentrations.

Thick Quaternary deposits of sand and gravel yield good quality water, although some supplies require treatment for iron.

NEW YORK

Natural ground water in both the consolidated and unconsolidated rock aquifers of New York is generally of excellent quality, but hard. Specific problems do occur, however, which are usually related to the presence of some distinct geologic rock units and are most apparent in the shale and limestone aquifers. Table 19 is a compilation of chemical analyses of selected constituents in natural ground waters.

The principal natural problem is the occurrence of high iron and manganese concentrations in water from the major aquifers. The presence of excessive iron and manganese results from the leaching of these ions from rocks and sediments by acidic circulating ground water. Certain consolidated rocks are commonly high in iron sulfide minerals and trapped hydrogen sulfide gas. When dissolved in water, the sulfides produce an acidic solution. The presence of sulfide minerals is common in carbonate rocks of western New York and shales across the state; therefore iron and manganese problems are also common in these aquifers.

Table 19. CHEMICAL ANALYSES OF GROUND WATER IN NEW YORK. (Concentrations in milligrams per liter.) 73 through 87)

Location	Rock Type	Iron (Fe) N	Iron (Fe) Range	Iron (Fe) M	Chloride (Cl) N	Chloride (Cl) Range	Chloride (Cl) M	Sulfate (SO_4) N	Sulfate (SO_4) Range	Sulfate (SO_4) M
West										
Buffalo-Niagara Region	Lh [a)]	1	1.0	-	14	54 - 6,300	900	14	18 - 3,620	547
	Lc	24	0.05 - 8.4	0.71	67	2.2 - 1,530	49	64	62 - 1,600	209
	Mh	1	0.07	-	21	4.5 - 2,520	34	21	134 - 1,950	1,120
	Uc	2	0.08 - 5.6	-	13	0.1 - 860	38	13	16 - 560	69
	Uh	4	0.10 - 0.53	-	85	1 - 1,000	28	85	0 - 789	21
	S [b)]	-	-	-	2	820 - 4,450	-	2	344 - 794	-
	T	3	0.03 - 0.98	-	8	1.5 - 461	68	8	17 - 644	55
Oswego River Basin	S	4	0.10 - 0.78	-	4	9.8 - 269	-	3	9.1 - 46	-
	Lh	2	0.03 - 0.43	-	2	18 - 10,000	-	2	0.2 - 0.9	-
	Lc	3	0.19 - 1.3	-	3	2.2 - 59	-	3	24 - 72	-
	Mh	10	0 - 3.5	0.43	14	3.6 - 21,200	64	11	439 - 3,510	1,320
	Uc	6	0.02 - 0.90	0.04	6	3 - 15	7	2	45 - 182	-
	S/G	47	0 - 2.4	0.22	50	0.2 - 42,500	18	17	0.7 - 3,360	129
	T	4	0.03 - 1.2	-	4	1.9 - 4.4	-	2	24 - 69	-
	Uh	8	0.06 - 0.58	0.12	8	2.1 - 6,690	9.3	6	3 - 1,310	8.4

N - Number of samples
M - Median
a) - Queenston shale and Clinton Group shale
b) - Albion Group

X - Crystalline rocks
Sh - Shale
S - Sandstone
T - Till
C - Carbonate rocks

Lh - Lower shale
Lc - Lower carbonate
Mh - Middle shale
Uc - Upper carbonate
Uh - Upper shale
S/G - Sand and gravel

Table 19 (continued). CHEMICAL ANALYSES OF GROUND WATER IN NEW YORK. (Concentrations in milligrams per liter.) 73 through 87)

Location	Rock Type	Total Hardness (as $CaCO_3$)			Total Dissolved Solids			pH		
		N	Range	M	N	Range	M	N	Range	M
Northeast										
St. Lawrence County	S	5	221 - 345	278	5	277 - 458	345	5	7.2 - 8.3	7.6
	C	42	41 - 9,420	283	36	240 - 20,900	692	35	6.8 - 8.3	7.5
	T	4	308 - 467	-	7	288 - 558	348	4	7.1 - 7.8	-
	S/G	4	52 - 405	-	3	295 - 432	-	4	6.7 - 7.5	-
Lake Champlain - Upper Hudson Region	X	-	89 - 134	-	-	89 - 200	-	-	6.8 - 8.0	-
	Sh	2	220 - 283	-	2	268 - 355	-	2	7.2 - 7.9	-
	S	21	48 - 342	242	21	81 - 550	286	21	6.3 - 8.2	7.6
	T	-	32 - 129	-	-	60 - 134	-	-	7.5 - 8.1	-
	S/G	-	39 - 526	-	-	66 - 625	-	-	6.7 - 8.4	-
	C	14	84 - 318	175	13	113 - 378	226	15	7.2 - 8.1	8.0
Southeast										
Albany Region	X	4	50 - 200	-	4	60 - 261	-	4	6.5 - 7.5	-
	Sh	51	1 - 5,340	100	35	105 - 21,700	313	51	6.0 - 9.3	7.5
	S	5	30 - 280	108	5	39 - 282	148	5	6.8 - 7.8	7.6
	T	9	30 - 508	172	4	95 - 359	-	7	6.3 - 8.1	7.0
	S/G	58	32 - 390	159	31	29 - 505	222	54	6.3 - 8.4	7.6
	C	10	42 - 360	240	10	84 - 534	315	10	6.4 - 7.5	7.4
Lower Hudson Region	X	11	15 - 173	104	10	60 - 276	183	11	6.1 - 9.6	7.4
	Sh	6	36 - 291	115	6	192 - 425	225	6	6.6 - 8.3	7.8
	S	22	24 - 210	97	11	48 - 296	168	20	5.8 - 8.4	7.6
	T	18	18 - 269	38	9	36 - 419	55	17	6.0 - 8.3	6.8
	S/G	47	22 - 480	95	14	115 - 600	181	41	6.1 - 8.4	7.2
	C	30	106 - 590	185	15	178 - 513	287	31	7.0 - 8.1	7.4
Long Island	S/G	84	2 - 381	21	89	16 - 763	76	91	4.5 - 7.7	6.3

Table 19 (continued). CHEMICAL ANALYSES OF GROUND WATER IN NEW YORK. (Concentrations in milligrams per liter.) 73 through 87)

Location	Rock Type	Iron (Fe) N	Iron (Fe) Range	Iron (Fe) M	Chloride (Cl) N	Chloride (Cl) Range	Chloride (Cl) M	Sulfate (SO_4) N	Sulfate (SO_4) Range	Sulfate (SO_4) M
Northeast										
St. Lawrence County	S	5	0.09 - 0.90	0.39	5	6 - 38	14	5	45 - 79	70
	C	18	0 - 15	0.20	55	1 - 12,800	46	41	0 - 2,020	92
	T	2	0 - 0.08	-	10	1.2 - 49	16	4	48 - 156	-
	S/G	2	0.14 - 0.16	-	5	0.8 - 32	15	2	36 - 64	-
Lake Champlain - Upper Hudson Region	X	-	0.01 - 2.0	-	-	1.8 - 29	-	-	0.2 - 22	-
	Sh	2	0.25 - 0.29	-	2	2.6 - 16	-	2	18 - 48	-
	S	21	0 - 9.1	0.58	21	1 - 115	10	21	10 - 101	38
	T	-	0.09 - 0.26	-	-	0 - 2	-	-	1.8 - 10	-
	S/G	-	0.01 - 2.6	-	-	0.1 - 104	-	-	0.4 - 227	-
	C	12	0.02 - 10	0.15	15	1 - 9	2.4	14	3.8 - 61	18
Southeast										
Albany Region	X	4	0.03 - 0.38	-	4	0.8 - 2.2	-	4	2.6 - 32	-
	Sh	48	0.03 - 43	0.2	66	0.4 - 10,800	15	36	0 - 302	30
	S	5	0.1 - 0.25	0.2	5	0.2 - 15	3.0	5	9.4 - 20	14
	T	6	0.03 - 0.5	0.15	29	0.4 - 198	15	4	6.8 - 46	-
	S/G	60	0 - 2.5	0.1	85	0.2 - 76	8.2	36	1 - 109	26
	C	10	0.03 - 1.3	0.16	10	0.2 - 31	7.1	10	17 - 55	30
Lower Hudson Region	X	11	0.1 - 2.4	0.19	10	0.6 - 18	8.4	10	9.3 - 62	24
	Sh	6	0.03 - 0.97	0.39	6	2.4 - 26	5.8	6	10 - 87	45
	S	19	0 - 0.74	0.2	22	1.1 - 35	6.4	13	3 - 64	24
	T	16	0.03 - 3.0	0.1	18	1 - 55	2.1	14	6 - 56	12
	S/G	42	0 - 4.6	0.10	46	1.6 - 480	4.6	33	6.6 - 190	22
	C	27	0.03 - 1.0	0.11	33	0.7 - 60	4.0	22	4 - 182	29
Long Island	S/G	89	0 - 17	0.13	83	2.5 - 235	7.6	91	0.2 - 160	11

Table 19 (continued). CHEMICAL ANALYSES OF GROUND WATER IN NEW YORK. (Concentrations in milligrams per liter.) 73 through 87)

Location	Rock Type	Total Hardness (as $CaCO_3$)			Total Dissolved Solids			pH		
		N	Range	M	N	Range	M	N	Range	M
West										
Buffalo-Niagara Region	Lh [a)]	14	219 - 4,840	1,154	8	533 - 11,200	2,820	14	5.7 - 7.8	7.2
	Lc	63	120 - 2,660	482	58	299 - 5,000	689	64	6.6 - 8.1	7.2
	Mh	21	319 - 2,780	1,570	1	1,500	-	21	7.0 - 8.0	7.4
	Uc	13	200 - 1,040	338	2	1,720 - 2,000	-	13	6.8 - 7.7	7.3
	Uh	85	52 - 1,180	232	4	193 - 841	-	85	6.8 - 8.3	7.4
	S [b)]	2	1,260 - 2,790	-	1	2,790	-	2	6.5 - 7.1	-
	T	8	137 - 1,310	367	3	154 - 878	-	8	6.1 - 8.5	7.7
Oswego River Basin	S	4	66 - 185	-	3	141 - 642	-	4	7.2 - 7.9	-
	Lh	2	96 - 2,710	-	2	219 - 16,200	-	2	7.3 - 7.6	-
	Lc	3	118 - 300	-	1	344	-	3	7.6 - 7.8	-
	Mh	14	490 - 5,050	1,400	4	1,560 - 4,320	-	13	7.0 - 7.6	7.4
	Uc	6	319 - 680	425	2	372 - 531	-	6	7.3 - 7.9	7.5
	Uh	6	10 - 1,280	137	6	80 - 13,200	193	8	6.5 - 7.9	7.0
	S/G	51	52 - 4,420	320	10	100 - 2,100	372	48	6.8 - 8.4	7.5
	T	4	136 - 600	-	1	199	-	4	7.5 - 7.9	-

Two problems which occur regionally are high total dissolved solids and hardness. Total dissolved solids are generally higher in the shale aquifer across the state than in any other consolidated rock aquifer. It also follows that total dissolved solids values for water from unconsolidated deposits overlying shale are generally higher than unconsolidated deposits overlying other rocks. Hardness is higher in wells in carbonate rocks, and in unconsolidated deposits overlying carbonate rocks.

In the eastern half of New York, high concentrations of iron and manganese are the major problems associated with water from the shale, limestone, and unconsolidated rock aquifers. However, other natural problems occur in specific areas. At the extreme northern border in the St. Lawrence River Basin, a large percentage of wells in two areas yield water with high concentrations of total dissolved solids. In the extreme northeast corner of the state, some wells penetrating the carbonate and the sandstone aquifers have reported total dissolved solids concentrations of greater than 500 mg/l. [86)]

One hundred miles west of this area, limestone is penetrated by many wells which produce highly mineralized ground water. Of 39 samples analyzed, 17 contained more than 500 mg/l of total dissolved solids, and two analyses were reported with nearly 20,000 mg/l. Chloride and sodium are the predominant ions; three wells were reported to have greater than 10,000 mg/l of chloride, and two of these were reported to have a sodium content over 3,500 mg/l. [87)]

The inland occurrence of mineralized and saline water is not unusual in the northeast. Periodic flooding by the sea has occurred throughout geologic time in the Paleozoic Era and most recently during the Pleistocene Period. Where the Paleozoic rocks were not flushed with fresh water before their burial, salt water may have been entrapped. Similarly, sea water that may have percolated into an aquifer during Pleistocene flooding may not yet be flushed out.

In Saratoga and Washington Counties, southeast of the Adirondack crystalline area, highly mineralized water is brought to the surface in wells and springs. This water is used at the famous Saratoga Spa and other spas in the region. [88,89)]

The aquifers of the western portion of New York exhibit the typical iron/manganese and hardness problems associated with their rock types. In addition, some unusual geologic conditions have caused other ground-water problems. Generally, the three oldest rock units have severe water-quality problems. The lower shale and middle shale aquifers are typically salty at depth and may receive sulfate-charged circulating water from the adjacent Lockport dolomite. In the west-central area (Wayne County) near Rochester, reported analyses of the water from wells in the lower shale aquifer show concentrations that approached 9,000 mg/l of total dissolved solids and 3,500 mg/l of chloride; reported analyses for wells in the middle shale aquifer show concentrations near 5,500 mg/l in total dissolved solids, and a water sample from one well (for which total dissolved solids analysis was not run) shows a concentration of 21,000 mg/l of chloride. The middle shale aquifer is known to contain some evaporite beds. Sulfate concentrations of water from wells in the middle shale aquifer were reported to be near 2,500 mg/l. [90] In the next most southerly county (Ontario) the quality of the middle shale aquifer does not seem to be as poor. The maximum total dissolved solids concentration reported is 2,360 mg/l and the maximum reported sulfate concentration is 1,490 mg/l; unconsolidated aquifers above the middle shale yield water with a maximum total dissolved solids of 2,500 mg/l. [91]

At the western edge of the carbonate bands in New York (near Niagara Falls), analyses of water from all five of the principal aquifers indicate relatively poor quality. Figure 19 shows how ground-water quality could become affected by natural inter-aquifer movement of mineralized water. Total dissolved solids content here is commonly greater than 800 mg/l, and in the upper part of the middle shale aquifer, the range is reported as 800 to 5,000 mg/l. [92] The lower shale aquifer in this area discharges connate water averaging 2,600 mg/l of total dissolved solids and 646 mg/l of chloride. [93]

Farther south, in the area of the upper-shale aquifer, water quality is generally adequate in wells in both the upper shale and overlying sand and gravel aquifers. However, a few wells in shale yield highly mineralized water with total dissolved solids greater than 1,000 mg/l and chlorides greater than 500 mg/l. [94] It was originally believed that the only source of the minerals in this water was natural and caused by the presence of evaporite deposits below the lower shale aquifer. However, it is now becoming apparent that improperly constructed or improperly plugged abandoned oil and gas wells are acting as conduits to bring saline water from depth into the surface aquifers. The volume of contaminated water in the shallow aquifers is unknown compared to the total volume of mineralized ground water. However, the rising chlorides observed in water from the sand and gravel aquifer provide a clue that the volume may be significant.

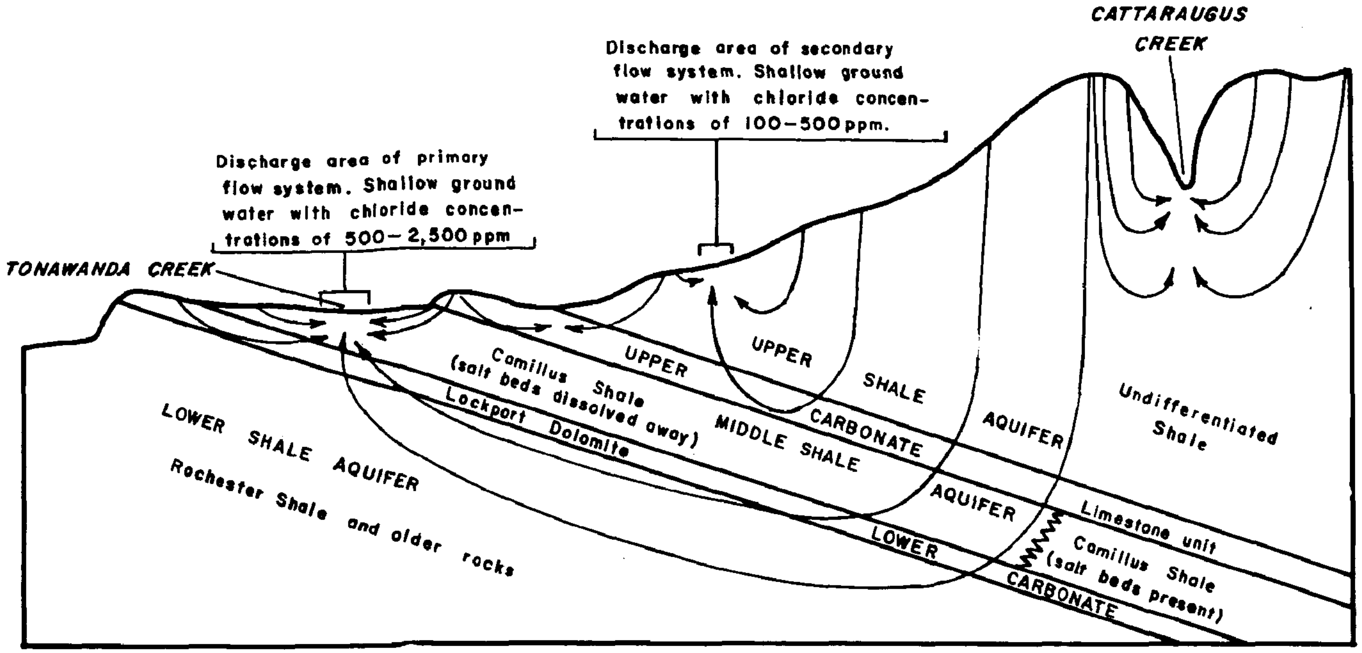

Figure 19. Inferred regional circulation of ground water to explain variations in chemical constituents in ground water at shallow depth in western New York [92])

Unconsolidated deposits of glacial origin and unconsolidated deposits associated with the Coastal Plain area of Long Island yield water which is generally of good quality. Isolated problems that occur are normally related to high concentrations of iron and manganese and low pH.

PENNSYLVANIA

Natural ground-water quality is variable in the major aquifers of Pennsylvania, and a high degree of mineralization has been encountered in some areas. Selected analyses of water from wells in various aquifers around the state are tabulated in Table 20.

A water-quality problem in Pennsylvania, as in nearly all of the states in the study area, is the occurrence of high iron and manganese concentrations in water from wells in unconsolidated deposits. Although Table 20 does not record chemical analyses for manganese, it can be seen that median values of iron concentrations is high in wells in the unconsolidated material of the Coastal Plain (southeast) and Unglaciated Appalachians (south central). Not so obvious, but still significant, are the high range values for water from wells in the northwest, north central, and southwest areas. The high iron and manganese concentrations in ground water in these deposits appear to result from leaching of sediments by natural acidic percolating water.

It can also be seen that iron concentration is rather high in ground water in late Paleozoic sedimentary rocks. To some extent, this phenomenon is related to processes of mineralization, where seasonal fluctuations of the water table expose to oxidation the iron-bearing minerals that commonly occur in these rocks. This problem is aggravated where coal mining has caused an artificial but temporary lowering of the water table.

Median and range values for calcium, magnesium and bicarbonate are often high in the aquifers of Pennsylvania. Two reasons for their prominence in consolidated rock aquifers are the frequency of interbedded limestones in the Paleozoic clastic sequences and, in the north, the volume of carbonate rock debris in the glacial overburden from which recharge is derived.

A major problem associated with the western region of Pennsylvania is the general occurrence of highly-mineralized ground water in the shallow subsurface (less than 500 feet deep). [2] In the Pittsburgh area especially, it has been stated that the ground water in bedrock more than 100 feet

Table 20. CHEMICAL ANALYSES OF GROUND WATER IN PENNSYLVANIA. (Concentrations in milligrams per liter.) 95 through 104)

Location	Rock Type	Iron (Fe) N	Iron (Fe) Range	Iron (Fe) M	Sulfate (SO_4) N	Sulfate (SO_4) Range	Sulfate (SO_4) M	Total Dissolved Solids N	Total Dissolved Solids Range	Total Dissolved Solids M
Northeast	SD	22	0.01 - 6.6	0.07	61	1 - 1,266	10	65	10 - 2,102	124
	PD	6	0.04 - 3.4	0.09	11	1 - 66	6	14	11 - 393	56
	U	7	0.01 - 0.12	0.02	25	1 - 97	9.4	27	10 - 134	50
Southeast	X	87	0.02 - 25	5.2	38	15 - 412	138	39	58 - 1,810	357
	C	52	0 - 1.1	0.07	52	14 - 72	43	52	218 - 805	343
	Tr	-	-	0.14	-	-	38	-	-	302
	U	70	0.02 - 429	1.75	86	1.1 - 1,340	21	78	124 - 4,270	239
North Central	SD	15	0.1 - 0.5	0.2	16	2 - 470	10	16	18 - 3,155	254
	PD	12	0.1 - 22	1.5	13	3 - 345	6	13	21 - 584	54
	U	12	0.01 - 14	0.10	12	2 - 60	10	12	53 - 972	137
South Central	C	5	0.01 - 0.03	0.02	9	3 - 27	10	9	59 - 312	206
	SD	15	0.01 - 16	0.18	44	2 - 1,764	20	43	14 - 2,565	218
	PD	11	0.11 - 28	0.4	32	2 - 630	16	30	19 - 1,042	163
	U	2	0.31 - 5.8	-	2	14 - 40	-	2	113 - 227	-
Northwest	SD	5	0.02 - 0.84	0.39	7	2 - 48	13	7	136 - 1,488	177
	PD	72	0 - 42	1.2	50	1.5 - 227	18	77	23 - 3,826	311
	U	42	0 - 4.03	0.14	41	5.1 - 331	31	53	119 - 881	230
Southwest	PD	80	0.05 - 51	0.52	80	2.3 - 1,618	23	78	62 - 8,595	321
	U	9	0.07 - 108	0.16	9	5 - 120	77	8	83 - 485	316

X - Crystalline rocks
C - Cambrian and Ordovician carbonates
SD - Silurian and Devonian sedimentary rocks
PD - Post Devonian sedimentary rocks
Tr - Triassic sedimentary rocks
U - Unconsolidated deposits
N - Number of samples
M - Median

Table 20 (continued). CHEMICAL ANALYSES OF GROUND WATER IN PENNSYLVANIA. 95 through 104)
(Concentrations in milligrams per liter.)

Location	Rock Type	Total Hardness (as $CaCO_3$) N	Range	M	Chloride (Cl) N	Range	M
Northeast	SD	62	6 - 1,447	94	64	1 - 254	3
	PD	14	4 - 148	32	12	1 - 168	2
	U	23	3 - 198	28	27	1 - 68	2
Southeast	X	42	52 - 780	232	62	13 - 400	62
	C	52	185 - 564	288	52	3.8 - 82	8.7
	Tr	-	-	218	-	-	9.7
	U	69	40 - 945	120	106	11 - 302	28
North Central	SD	16	15 - 544	98	16	1 - 1,820	27
	PD	13	10 - 388	52	13	0 - 142	4
	U	12	29 - 347	104	12	1.6 - 465	11
South Central	C	9	51 - 273	192	9	0.6 - 28	2.0
	SD	44	10 - 1,994	172	44	0.2 - 1,250	6
	PD	32	14 - 852	101	31	1 - 70	3
	U	2	74	-	2	24 - 72	-
Northwest	SD	7	34 - 137	99	7	2.4 - 716	10
	PD	77	1 - 622	110	77	1 - 1,868	34
	U	54	43 - 582	148	54	1.2 - 190	14
Southwest	PD	78	13 - 1,843	160	80	0.5 -60,000	14
	U	9	29 - 350	136	9	4 - 145	18

below the valley bottoms is usually too highly mineralized for most uses.[103] The problem is indicated by the high median values of total dissolved solids in the northwest and southwest areas. Additionally, saline water is reported locally across the northern and western parts of the state, as indicated in Table 20 by the high range values for chloride concentrations. The high values may be primarily associated with natural oil seeps which bring saline water to the surface, in addition to improperly plugged or abandoned oil and gas wells.[104]

RHODE ISLAND

The natural chemical quality of ground water in Rhode Island is generally excellent. Table 21 is a compilation of chemical analyses of selected constituents in natural ground waters. Total dissolved solids concentration rarely exceeds recommended U. S. Public Health Service limits. For 85 samples of ground water from various aquifers, no analysis exceeded 500 mg/l in total dissolved solids.[51] Water is generally soft to moderately hard, few analyses exceeding 120 mg/l of hardness.

As in most of New England, the prevailing natural problem appears to be the occurrence of excessive concentrations of iron and manganese. In the Providence area, waters from most of the wells in the sedimentary rock aquifer contain objectionable amounts of iron, as do about one-half of the wells in outwash.[106] In the Woonsocket basin, many wells in the Greenville area have iron concentrations of 6 to 7 mg/l; some wells in overlying unconsolidated deposits also produce water with high iron.[107] On Block Island, iron concentrations as high as 22 mg/l have been reported for ground-water samples from the unconsolidated deposits.[108]

One natural water-quality problem in Rhode Island is related to its long coastline. In the southern part of the state and on Block Island, salt spray and relatively high quantities of dissolved salt in precipitation cause high concentrations of chloride and sodium in water from the various aquifers. However, these levels rarely approach the upper limit of 250 mg/l for chloride recommended by the U. S. Public Health Service. On Block Island, for example, chloride concentrations in perched water bodies range from 14 to 248 mg/l, with a median of 34 mg/l.[108]

VERMONT

Very little published data are available on natural ground-water quality in Vermont. According to one report, both

Table 21. CHEMICAL ANALYSES OF GROUND WATER IN RHODE ISLAND. (Concentrations in milligrams per liter.) 105 through 109)

Location	Rock Type	Iron (Fe) N	Iron (Fe) Range	Iron (Fe) M	Sulfate (SO_4) N	Sulfate (SO_4) Range	Sulfate (SO_4) M	Chloride (Cl) N	Chloride (Cl) Range	Chloride (Cl) M
Providence Co.	X	19	0 - 0.4	0.05	18	4.3 - 92	20	17	1.9 - 17	9
	S	14	0 - 24	0.34	13	5.1 - 66	29	17	5 - 37	15
	S/G	35	0 - 5.2	0.05	22	5.4 - 109	22	36	3 - 61	14
Kent Co. and Washington Co. and Block Island	X	7	0.03 - 25	0.5	6	9.7 - 65	27	8	0.5 - 35	15
	S/G	19	0 - 0.71	0.03	18	4 - 32	8.1	19	3.8 - 38	8
Newport Co. and Briston Co.	X	4	0 - 5	-	2	7.4 - 19	-	4	12 - 55	-
	S/G	9	0.03 - 0.5	0.08	7	13 - 34	21	9	9 - 55	17

Location	Rock Type	Total Dissolved Solids N	Total Dissolved Solids Range	Total Dissolved Solids M	Total Hardness (as $CaCO_3$) N	Total Hardness (as $CaCO_3$) Range	Total Hardness (as $CaCO_3$) M	pH N	pH Range	pH M
Providence Co.	X	19	22 - 299	117	18	8 - 182	58	17	6.1 - 8.5	7.2
	S	11	53 - 319	157	12	22 - 228	103	8	6.3 - 7.8	7.2
	S/G	20	20 - 168	70	21	17 - 179	53	25	5.6 - 8.6	6.5
Kent Co. and Washington Co. and Block Island	X	3	91 - 227	-	4	34 - 198	-	4	6.3 - 7.3	
	S/G	18	33 - 147	52	18	11 - 82	27	14	5.9 - 7.4	6.7
Newport Co. and Briston Co.	X	1	161	-	2	89 - 110	-	1	7.4	-
	S/G	7	61 - 164	99	7	21 - 62	32	3	6.5 - 7.1	-

X - Crystalline rocks
S - Sedimentary rocks
S/G - Sand and gravel

N - Number of samples
M - Median

ground-water and surface-water quality in Vermont are generally good. Of 10 cities using ground and/or surface water, only two supplies exceeded 100 mg/l of either dissolved solids or hardness. [51]

However, the state does have areas with specific problems. In northwestern Vermont, especially from Middlebury to Colchester in the Champlain Lowland, it has been noted that many wells yield water high in sulfides and hydrogen sulfide. [110] South of Lake Dunmore in the Vermont Lowland, local rock-well drillers report a problem with "okra", limonite-pellet concretions which move through and clog fractures. [111] There are also frequent reports of high concentrations of iron and manganese in water from individual wells throughout the state.

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SECTION VI

SOURCES OF GROUND-WATER CONTAMINATION

DEFINITION OF THE PROBLEM

As discussed in the previous section, natural ground-water quality in the region is associated with geologic and hydrologic processes. Although problems of natural poor-quality water are unavoidable and can limit the development of ground water in specific areas, only an extremely small number of these instances of mineralization present a potential health hazard. Furthermore, overall ground-water quality in the northeast can be described as good to excellent. Relatively few public-supply systems find it necessary to treat well water to correct biological and chemical problems related to natural conditions.

On the other hand, contamination or degradation of water quality due to man's actions can be avoided. Problems of this type often represent severe hazards, both to the ground-water resource itself and to public health. This section describes the principal sources of contamination in the northeast and discusses their importance in the region. However, before dealing with such specific details as case histories, frequency of occurrence, and regional trends, it is important to define the problem of ground-water contamination and to point out the cause for concern.

For many years, public agencies on all levels of government have been concerned about the contamination of surface waters. The loss of rivers and lakes as sources of water supply and recreation can have a tremendous impact on a particular region, leading to construction of a long pipeline to import acceptable water, for example, or the closing of a popular swimming area to local residents. Degradation of the quality of water in a stream or lake can be rather obvious with discoloration, odor, and floating debris.

Problems of ground-water contamination, on the other hand, have never received much attention because they are usually local in nature, and the effects are hidden from view. Only when a regional water source is threatened, due to such problems as salt-water encroachment and widespread pollution from septic tanks, are broad controls recommended and implemented. However, protection of ground-water resources from all types of pollutants is an essential part of any program involving the solution of environmental problems. In many ways, the correction of ground-water quality degradation is considerably more complex than in the case of surface waters.

A discussion of the impact of ground-water contamination in the northeast takes on many aspects including:

1. The important role of ground water as a water-supply source.

2. The hidden and often misunderstood nature of ground-water pollution and the resulting health and other hazards.

3. The dependence of surface-water quality on ground-water quality.

4. The problems involved in monitoring ground-water quality.

5. The technical difficulties and high costs associated with the investigation, control, and correction of ground-water pollution.

Importance of the Resource

In the 11 northeastern states covered in this report, ground water plays a major role in meeting the water-supply requirements of communities, individual homes and commercial establishments, self-supplied industrial facilities, and irrigated farm lands. Total ground-water use in the region in 1970 has been estimated at more than 3.4 billion gallons per day, which is 18 percent of all the water diverted for all purposes exclusive of that used for generation of thermoelectric and hydroelectric power. [1)]

Twenty percent of the water served by community systems is derived from wells. Of even greater significance is the fact that the vast majority of individual utilities is dependent upon ground water because this source of supply is generally less costly to develop and treat than surface water. Thus, the smaller water purveyors use wells and springs, where feasible, rather than surface reservoirs, lakes, and rivers. For example, two thirds of the 378 public water-supply systems in New Jersey use ground water to meet at least a portion of the demands of the residents they serve. [2)] It should be noted also that some of the larger municipalities in that state, such as Atlantic City and Camden, are included in the two-thirds. A similar statistic holds true for Maryland, where 43 out of the 65 community water systems serving a population of 1,000 or more are completely dependent upon ground-water sources. [3)] In New York, at least two and one-half million urban residents are drinking well water supplied by 650 municipal utilities. [4] Connecticut estimates 600,000 persons are served by public water supplies using ground water. [5]

Ground water plays an even more significant role with regard to rural population or those not served by community systems. The rapid growth of suburbs after the Second World War in areas around major cities in the region has outpaced the ability of local utilities to build the necessary facilities to serve these outlying developments. Consequently, more and more homes and small commercial establishments have constructed their own on-site water supplies. Invariably, they depend on a drilled well. The widespread use of ground water is possible because rock formations normally are capable of yielding at least the few gallons per minute required to supply a single home or store.

There are probably several million domestic wells presently in use within the 11 states. Table 22 shows the estimated number of wells by state constructed in 1964 in the region. The 78,312 total for that one year represents mostly domestic wells.

Statistics on self-supplied industries in the study area are scanty, but the 1970 U. S. Geological Survey compilation (see Table 1) shows a total ground-water use of 1.4 billion gallons per day. [1] Many large manufacturing plants are either located beyond the service areas of public utilities or require such large quantities of high-quality water that economics and the need for reliability dictate development of an independent ground-water source. In many cases, ground water is the only readily available supply of water. For example, in the highly industrialized area along the lower Delaware River, a large number of factories both in New Jersey and Pennsylvania have tapped the prolific aquifers in the region in order to meet their water-supply needs and have used the river and its tributaries only for disposal of their treated wastes.

The potential for additional development of ground-water resources for all purposes in the region is quite large. For example, the ultimate daily yield of New Jersey's aquifers has been estimated at five billion gallons. [7] In New York State, glacial outwash deposits along the Mohawk River should be capable of yielding approximately 200 mgd; the potential of Long Island's aquifers has been placed at 1,200 mgd; and ground-water resources within the Susquehanna River Basin have been estimated at several hundred mgd. [8]

Ground water is available for development by wells every-

Table 22. NUMBER OF WELLS DRILLED IN THE NORTHEAST IN 1964. [6)]

State	Estimated number of wells drilled
Connecticut	6,500
Delaware	3,400
Maine	1,700
Maryland	6,902
Massachusetts	9,000
New Hampshire	4,400
New Jersey	3,440
New York	25,000
Pennsylvania	16,220
Rhode Island	250
Vermont	1,460
Total:	78,312

where within the region, and individual wells are presently pumped at rates ranging up to many thousands of gallons per minute. Reliance on ground water will increase in the region in the future, not only because of its widespread availability and the growing need for water but because surface waters are becoming increasingly more difficult and expensive to develop. Some principal causes for this include the rising costs of treating surface waters and the stricter regulations being imposed by public health agencies for their treatment. Another involves the problems inherent to obtaining large tracts of land for surface reservoirs. In addition, there is the competition for surface-water rights and the more active environmental concern over the effects of surface-water diversions. Finally, the extreme drought conditions experienced in the region in the early 1900's revealed to many water managers the vulnerability of surface water during adverse climatic conditions. On the other hand, ground water was shown to be a more reliable water source. Because of this, a large number of high-capacity wells have been installed as a back-up system for municipal and industrial surface-water supplies.

In summary, the importance of ground water in the northeast is obvious. The availability of this high-quality water source is essential to the physical and economic well-being of the region, and the loss of aquifers or even individual wells due to contamination, which can be avoided by proper controls, is unacceptable.

Health and Other Hazards

In order to fully understand health and other hazards associated with ground-water contamination, it is necessary to review the principles governing the movement within the ground-water system of a water body containing pollutants. Most problems of contamination begin when an objectionable fluid arrives at the water table. The fluid may have leaked out of an unlined industrial-waste lagoon, for example, or could have been spilled on the land surface from a ruptured oil storage tank. Another source of contamination is the leaching by precipitation of salt in stockpiles, solid waste in landfills, and fertilizers and pesticides spread on the land surface. In other words, the rain water is contaminated by contact with the soluble solid material either stored or spread on the land surface, and then slowly seeps downward into the underlying aquifer under the influence of gravity. Finally, the pollutant may have been discharged directly into the subsurface from septic tanks, leaky buried pipes or recharge wells.

Once the fluid containing the pollutant reaches the water table, it becomes responsive to the local pattern of ground-water movement, and from that time on, its velocity and direction of travel will be governed primarily by the laws of fluid movement in saturated materials. Ground water is almost always in motion through geologic formations, following paths from areas of intake to areas of discharge. The rate at which a liquid travels depends on the permeability of the deposits and on the hydraulic gradient in the ground-water system. In unconsolidated fine-grained sands, ground-water movement can be very slow, normally less than one foot per day. On the other hand, the rate of travel can be considerably greater if the contaminated fluid is moving through fracture zones or solution cavities of rock formations. Where pumping from wells has affected water levels in the aquifer in the area containing poor-quality ground water, the rate and direction of travel are also affected, and the pollutant will move more quickly, and toward the center of pumpage.

Other factors important to the occurrence and movement of contaminated ground water are the various processes that can affect the concentration of the pollutant, such as adsorption by the materials through which it passes, its density with respect to that of natural ground water, and the manner in which it spreads out or disperses as it travels. Adsorption or physiochemical forces can remove pollutants from solution and concentrate them on soil, clay, or fine-grained sand materials. Ion exchange and precipitation can also alter the character of the contaminant. Differences in density may cause a contaminant to travel in a direction somewhat different from that of the natural ground water. For example, gasoline will tend to float on the water table, even where there is a strong downward component of flow in the aquifer system. Dense brines introduced into a fresh-water aquifer may tend to sink under the influence of gravity, even though the natural direction of ground-water flow may be horizontal.

Of great importance is the fact that a pollutant contained in and moving through an aquifer tends to form an enclave or plume of contaminated water, extending along its flow path from the source where it was introduced to the point where it is either attenuated within the aquifer or is discharged to a well or a surface-water body such as a river, a lake, or the sea. Although dispersal in the direction of flow tends to reduce the concentration of a pollutant, the fluid normally does not fan out, and dispersal across the direction of flow is considerably less than the distance traveled. Figures 20 and 21 illustrate this effect in an unconsoli-

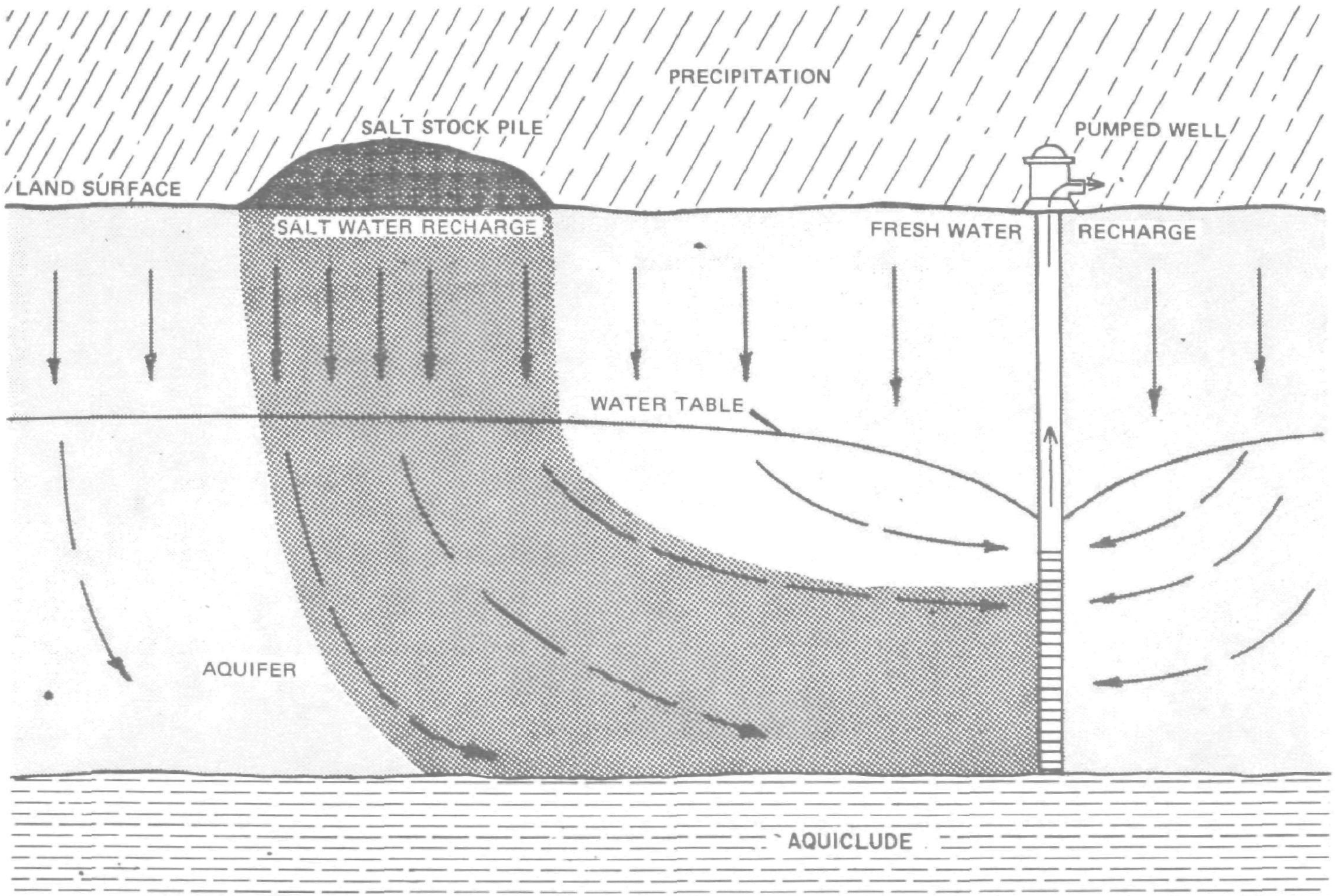

Figure 20. Flow pattern showing downward leaching of pollutants from a salt stock-pile and movement toward a pumped well [9)]

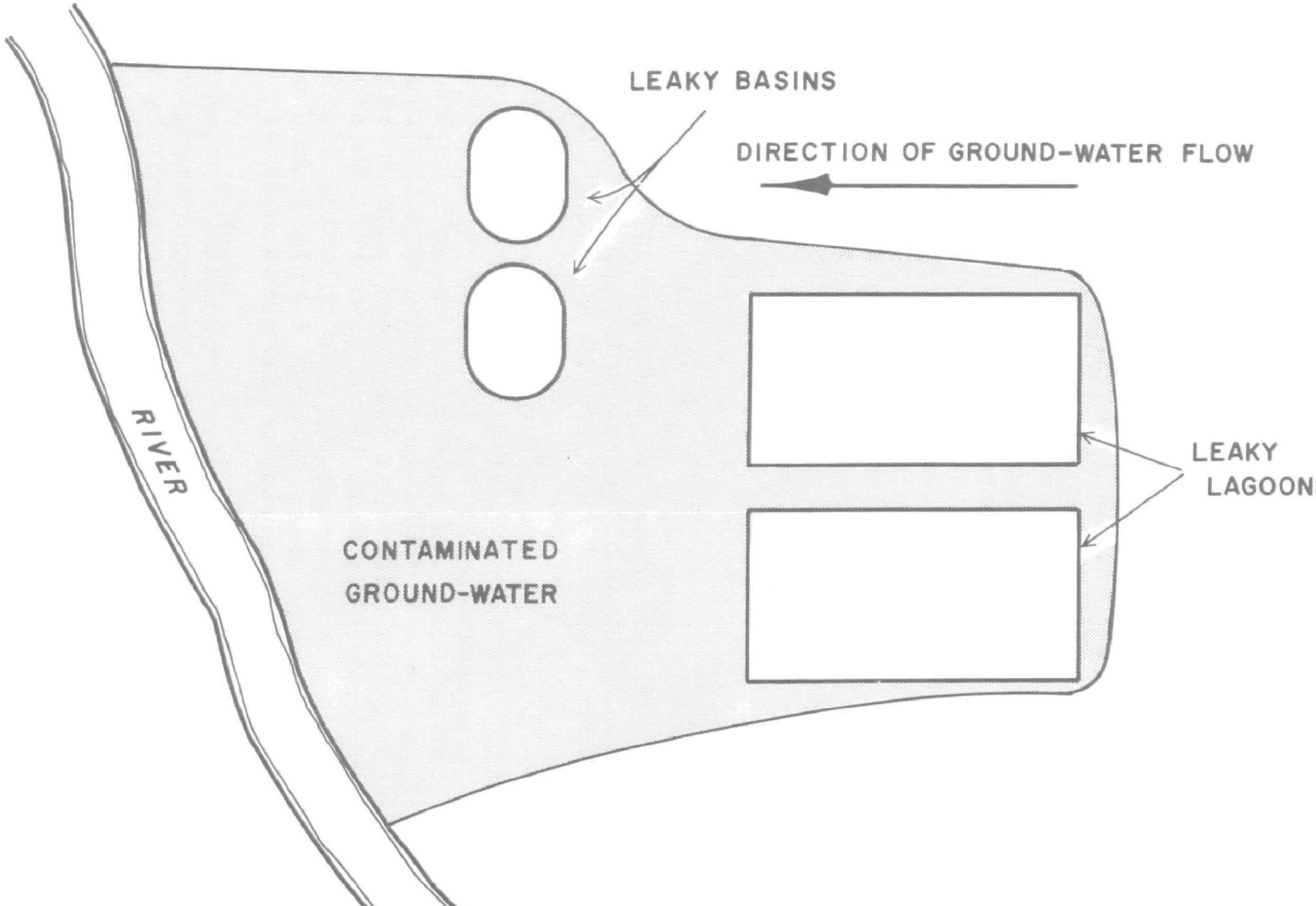

Figure 21. Plan view of plume of contaminated ground water caused by leakage from lagoons and basins into a water-table aquifer discharging into a river

dated sand and gravel aquifer. Movement of a contaminated fluid in the fractured zone of a rock aquifer is shown in Figures 22 and 23. In this latter case, dispersion is very slight and the fracture pattern controls the shape and areal extent of the plume. Finally, Figure 24 illustrates the phenomena associated with a light-density fluid such as gasoline and the associated plume.

Thus, one of the principal factors involved in ground-water contamination is the character of the environment in which it occurs. Although movement underground is normally slow, the pollutant is hidden from view, and given enough time it can travel undetected thousands of feet and even miles before reaching a well or a stream which is used, perhaps, as a source of drinking water. Two cases of contamination on Long Island, New York, illustrate these points. In one instance, industrial waste water containing high concentrations of chromium and cadmium has percolated to the water table principally through recharge basins into which the pollutant had been discharged. [11)] During a period of about 25 years, starting in the early 1940's, this seepage had formed a plume of contaminated ground water approximately 4,200 feet long, 1,000 feet wide, and as much as 70 feet thick. Presence of contamination went undetected for many years even though water from some private wells in the area used for drinking purposes had been affected. The maximum observed concentration of hexavalent chromium in the ground water was 40 mg/l and of cadmium was 10 mg/l. In contrast, the mandatory limits of concentrations in mg/l as set by the U. S. Public Health Service drinking water standards are no greater than 0.05 for hexavalent chromium and no greater than 0.01 for cadmium. In the second case, leachate from a municipal refuse dump has penetrated as much as 80 feet into the underlying sand and gravel aquifer, and the plume of contaminated ground water has extended, unobserved until recently, a distance of almost two miles. [12)] In another case, in Warren County, New Jersey, silver chloride from a photo-processing laboratory traveled over a mile from a seepage pit to domestic wells tapping a limestone aquifer. [13)]

Contaminated ground-water bodies containing concentrations of highly toxic materials are not uncommon throughout the northeast. One case in Pennsylvania is noteworthy where ground-water pollution, to the extent of 10,000 mg/l of arsenic, was discovered when an industrial site was sold, and a routine inspection by the new owner uncovered the fact that chemical wastes containing arsenical compounds previously discharged on the property had seeped down into the underlying aquifer. [14)] All in all, literally hundreds of cases of contamination of ground water by chemical constitu-

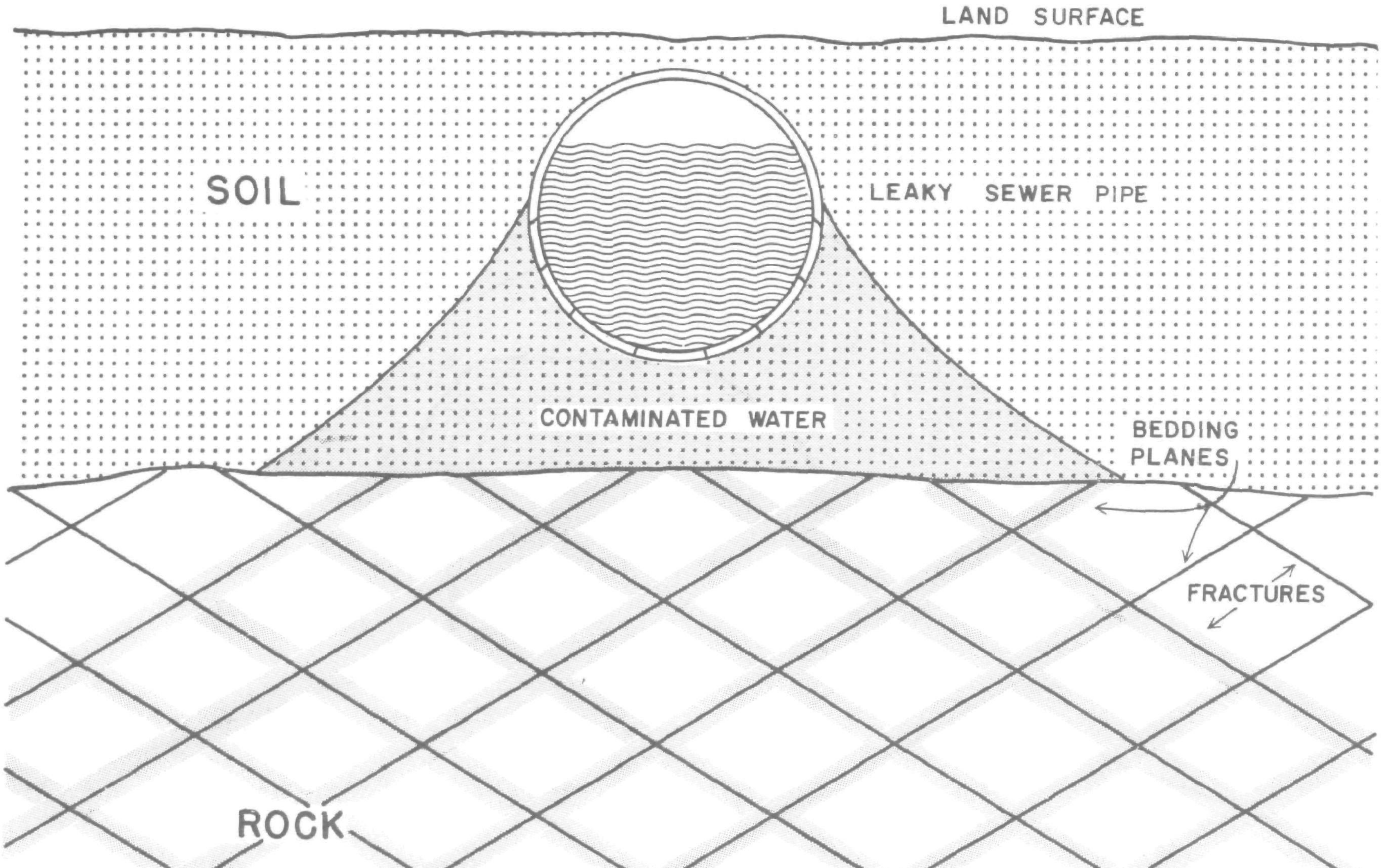

Figure 22. Downward movement of contaminated water from a leaky sewer into the bedding planes and fractures of a rock aquifer

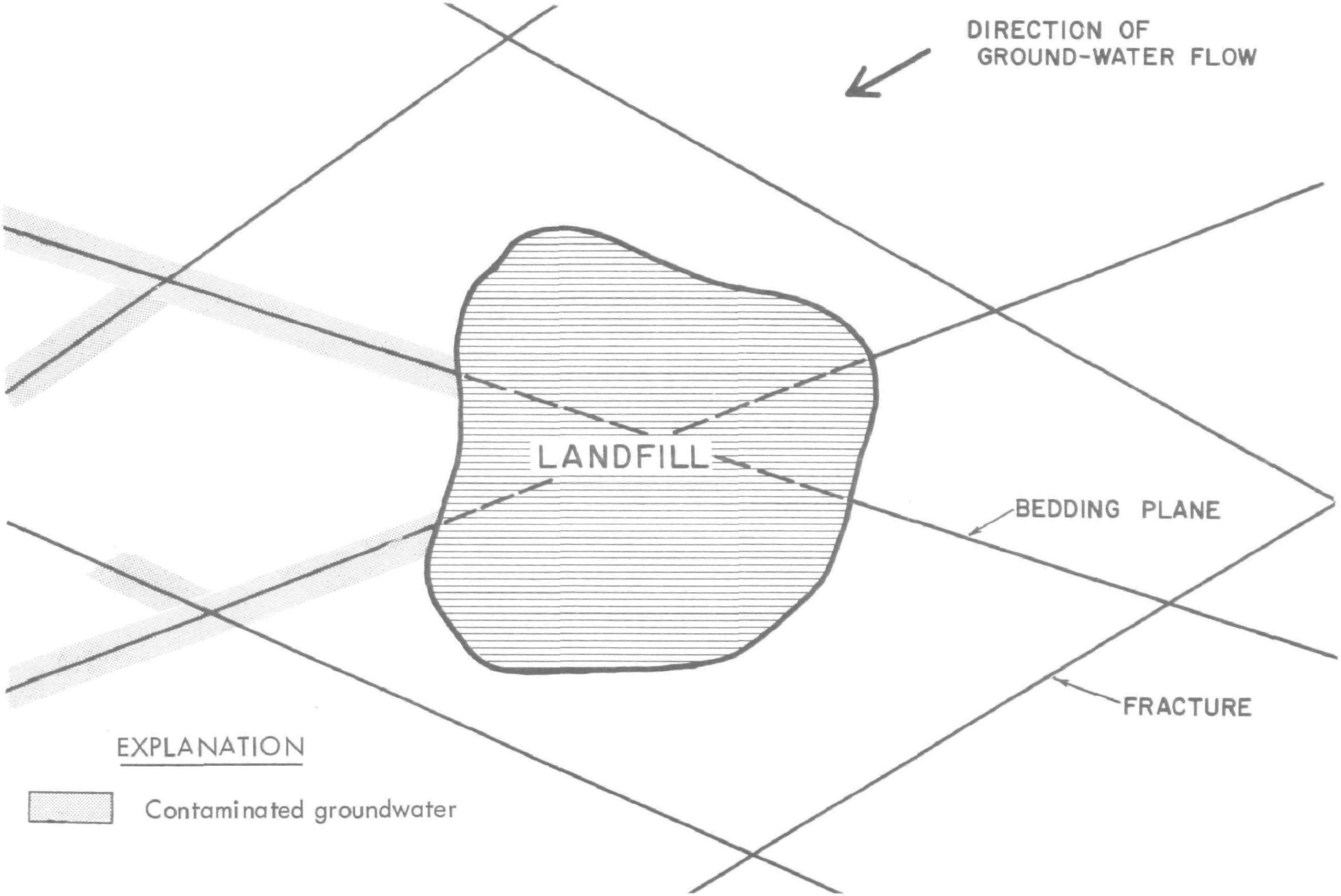

Figure 23. Plan view of contaminated ground water in bedding planes and fractures in a rock aquifer, caused by leachate from a landfill

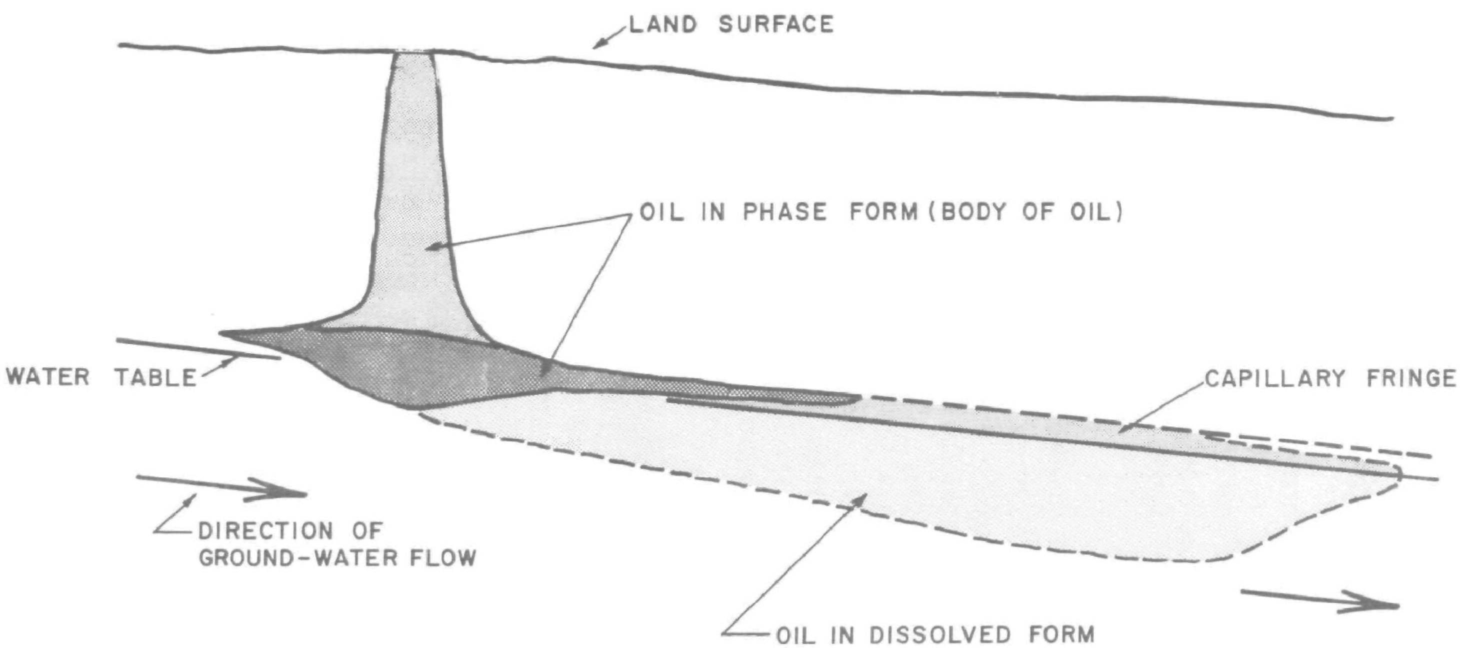

Figure 24. Movement of light-density fluid in the ground-water system. Contamination caused by a spill of hydrocarbons [10]

ents at levels greater than those set by drinking-water standards were uncovered in the northeast investigation. Undoubtedly, these known cases are only a very small percentage of those that have actually occurred in the area and remain undetected.

Another broad example of the hazards of ground-water contamination is the large number of instances in the northeast of the presence of hydrocarbons in the subsurface environment. Many of these cases involve the loss of private wells and public water-supply sources. In others, petroleum products have migrated into basements or underground conduits causing explosions and fires, or asphixiating people working in tunnels and sewers.

In upstate New York, two workers were killed recently when they were asphixiated while excavating a tunnel for a sewer line at an industrial plant. 15) The cause of the accident was traced to an unreported leak of toluene from a ruptured buried pipeline at the site. The hydrocarbon had remained floating on the water table in the vicinity of the leak. In Mechanicsburg, Pennsylvania, leakage of gasoline into a limestone aquifer resulted in the formation of an underground pool about one-third square mile in area. 16) Fumes from this pool seeped into basements of homes and resulted in several explosions.

Although the role that ground-water contamination plays in waterborne-disease outbreaks in this particular region is obscure, national surveys have shown that pollution of this source of water supply is an important factor. One major problem is that almost all privately supplied homes, most small community systems, and even some larger public utilities are supplied with untreated ground water. Therefore, the user is susceptible to bacteria and virus which have entered the well supply because of poor well construction, improper location with respect to septic tanks, or flooding of the land surface with polluted surface water such as sewage overflow.

Tables 23 and 24 show the results of an inventory of waterborne disease outbreaks in the United States related to ground-water sources for the period 1946-70. The more than 47,000 cases are significant, especially in view of the fact that most cases of illness related to contaminated ground water are probably not reported because they are either isolated cases, or no death has occurred, or the source of the disease was not suspected or investigated. For example, studies have revealed that only 35 to 50 percent of the outbreaks of disease in New York State had been reported to the

Table 23. INCIDENCE OF WATERBORNE DISEASE IN THE UNITED STATES, 1946-70, DUE TO SOURCE CONTAMINATION: GROUND WATER (UNTREATED) [17]

Cause	Private Outbreaks	Private Cases	Public Outbreaks	Public Cases	All Systems Outbreaks	All Systems Cases
Improper construction or location of well or spring						
Surface contamination nearby	21	640	1	2,500	22	3,140
Overflow or seepage of sewage	49	2,779	4	531	53	3,310
Seepage from abandoned well	1	50	-	-	1	50
Source of contamination not determined	8	235	1	400	9	635
Flooding	4	66	3	4,400	7	4,466
Contamination through creviced limestone or fissured rock	10	555	1	70	11	625
Chemical or pesticide contamination	4	17	-	-	4	17
Data insufficient to classify	46	2,001	3	16,350	49	18,351
Total:	143	6,343	13	24,251	156	30,594

Table 24. INCIDENCE OF WATERBORNE DISEASE IN THE UNITED STATES, 1946-70, GROUND WATER (CHLORINATED ONLY): TREATMENT OVERWHELMED DUE TO SOURCE CONTAMINATION.[17]

	Private		Public		All Systems	
Cause	Outbreaks	Cases	Outbreaks	Cases	Outbreaks	Cases
Overflow or seepage of sewage	-	-	3	16,273	3	16,273
Flooding	-	-	1	600	1	600
Contamination of raw-water transmission line or suction pipe	1	31	-	-	1	31
Total:	1	31	4	16,873	5	16,904

National Office of Vital Statistics during the period of 1938-60. [18]

The Relationship of Ground Water to Surface Water

One particular aspect of ground-water contamination often overlooked is the close relationship between ground-water and surface-water quality in the humid east. Most programs directed toward clean streams neglect to take into account the fact that ground-water discharge represents a major portion of flow in rivers in the northeast, and that during dry times of the year stream flow is often 100 percent ground-water discharge. Since the base flow (low flow) of most streams is ground water, and stream quality criteria is based on low flow quantities and quality, it is essential to maintain the quality of ground water to protect surface water.

Great effort is being directed toward improving the quality of surface water by seeking out sources of pollution discharging directly into streams and by requiring treatment or some other means for upgrading waste-water quality. Few investigations include an evaluation of the quality of ground water entering a particular stream, or an inventory of potential sources of ground-water contamination that are already or might ultimately discharge into a surface-water body.

To illustrate the relationship between surface water and ground water, it is helpful to review two detailed water-budget investigations that have been carried out in the region. The first, undertaken by W. C. Rasmussen and G. E. Andreasen of the U. S. Geological Survey, involved the 19.5 square-mile drainage basin of Beaverdam Creek, Maryland. [19] The chief purpose of the study was to measure and examine the various factors of the water cycle in a small, homogeneous drainage basin in an area of humid climate. Over a two-year period, it was found that ground-water drainage was almost 26 percent of the total precipitation and 72 percent of the total runoff carried by Beaverdam Creek. In a similar study, in the 287 square-mile Brandywine Creek Basin of Pennsylvania, F. H. Olmsted and A. G. Hely concluded that as an average for periods of several years, about two-thirds of the total runoff was base flow (chiefly ground-water discharge to the streams). [20]

A consequence of this close relationship has been recently investigated in the Ipswich and Shawsheen River Basins in Massachusetts. [21] Many housing developments in the metropolitan area of Boston are beyond the reach of municipal sewer systems and waste water, disposed of through septic tanks and cesspool systems, percolates to ground-water reservoirs and eventually reaches the streams. The investigators were able to use residual conductivity data from various sites within the two basins and develop a relationship between housing density per square mile and concentration of dissolved solids in base flow of streams. They concluded that in the range of housing densities observed (0 to 900 per square miles), dissolved solids in stream base flow can be expected to increase 10 to 15 mg/l per 100 houses per square mile. Also, the data indicated that most dissolved solids from septic tank systems reach the streams.

Numerous case histories have been uncovered in this investigation where contamination of ground water from a point source has significantly affected surface-water quality, at least in the general vicinity of the area into which the plume of contaminated ground water is discharging. These include problems related to leakage from lagoons, pits and basins receiving industrial wastes, mine drainage, spills, and percolation from landfills.

The Problem of Monitoring

Another major cause for concern with ground-water contamination is the problem of monitoring chemical and biological quality. The principal factors involved in the difficulty of monitoring this resource, and of providing a means for adequate warning against use of waters that may be harmful include the following:

1. The complex nature of aquifer systems and movement of ground water.

2. The large number of individual wells and springs presently being used.

3. The great variety of potential sources of contamination such as septic tanks, landfills, waste lagoons, etc., and their relative abundance in the northeast.

4. The lack of information on the quantity and type of chemical compounds being discharged to the air, soil, and water each day.

The movement of contaminants through aquifer systems, as described earlier, is dependent upon local and regional ground-water flow patterns, which, unlike surface streams, are not discernible with a visual or casual inspection. If a load of chemical waste is dumped into the Susquehanna River, for example, it is expected to move downstream, and it is not very difficult to determine in which direction the river is flowing. Furthermore, if the river is polluted with high counts of coliform bacteria, a sample dipped from almost any portion of the stream will give some indication of pollution. Not so with ground water: it is under laminar flow conditions and "downstream" may be in any direction, not necessarily related to surface topography at any particular location. Also, fluids of different densities and bacteria do not always move with the main body of ground water. They can float on the water table or sink toward the bottom of the aquifer.

Thus, determination of the direction of flow and areal extent of a contaminated ground-water body can be complex, and often can only be determined by a rather detailed and costly program of test drilling, and water-level and water-quality analyses. Even determining the shape of the water table may not be adequate for defining the problem, because this only indicates the horizontal direction of flow and gives no indication of how deeply a drop of contaminated fluid may descend along its path to a point of discharge.

For example, under some conditions, a drop of water may travel at fairly shallow depths from the place where it reaches the water table to the place where it leaves the ground-water system. Elsewhere, it may descend rather steeply to invade aquifers many hundreds of feet below the water table, and may move through those aquifers in a direction quite different from that followed by water in the shallow beds. Therefore, a proper evaluation of ground-water flow involves a knowledge of what is taking place in the vertical dimension as well as in the horizontal.

Figures 25 and 26 illustrate this principle. Both diagrams are hypothetical but are based on detailed studies of the hydrology of several solid waste landfills in the northeast. Figure 25 is a water-table map revealing that the highest point of the water table underlies the landfill area. According to one basic law of ground-water flow, the direction of movement of any drop of ground water in an unconfined aquifer is at right angles to the water-table contours. Thus, a drop starting at point "A", for example, will ultimately discharge into the adjoining marsh. Figure 26, which is a cross section through the hypothetical landfill along line X-X', shows, by means of arrows, the vertical pattern of flow. A drop of contaminated fluid reaching the water table at "B" would penetrate quite deeply into the underlying sediments before being discharged into the river. Actually, in the northeast region, abnormally high levels of

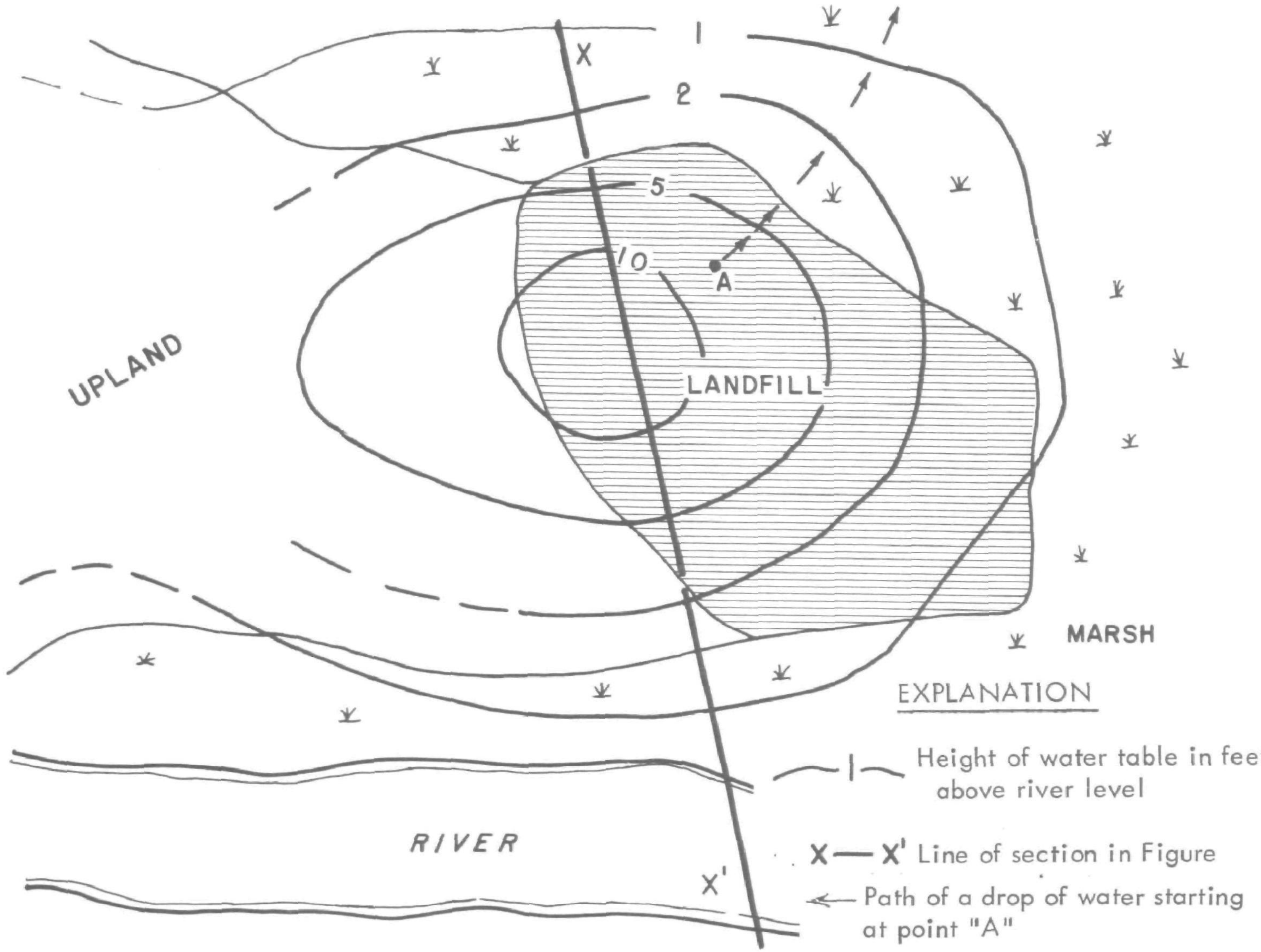

Figure 25. Plan view of water table contours associated with a landfill

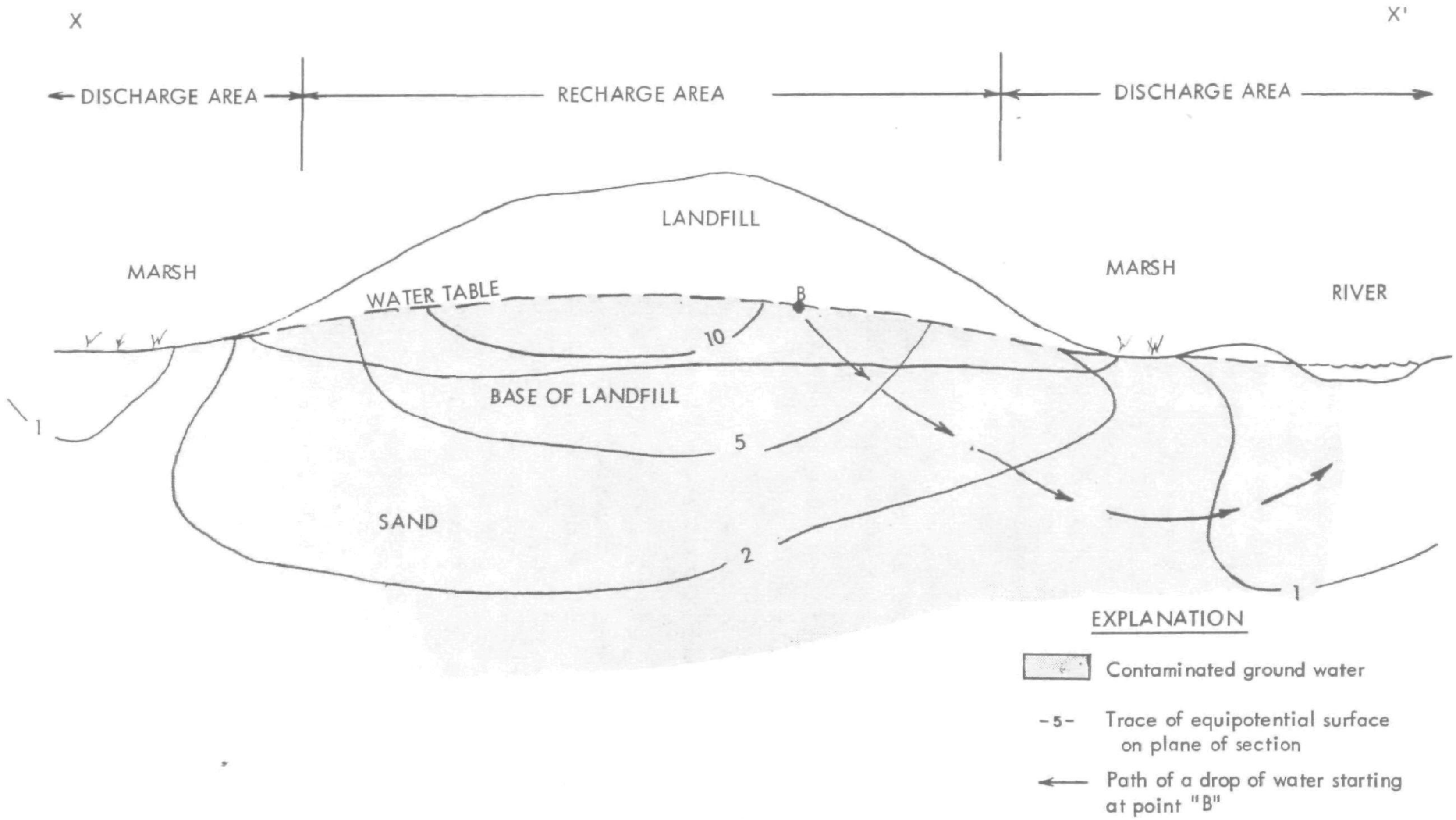

Figure 26. Generalized hydraulic profile beneath a landfill

iron, chloride, and hardness have been found in observation wells screened more than 100 feet below the water table beneath a landfill, indicating penetration to this depth of ground water that had become contaminated by contact with the refuse.

Stratification of sediments, such as a clay lens contained within a sand and gravel aquifer, can locally modify the movement of ground water and distort the overall pattern of flow. This is illustrated by a situation in southern New Jersey involving contamination of ground water from leaky waste lagoons, pits, and basins containing industrial wastes. As a protective device, the owner of the industrial site had drilled several monitoring wells but had not realized that they were all screened below a clay zone which was preventing the contaminant from penetrating deeply into the aquifer. For several years, water from the monitoring wells was periodically analyzed but showed no change compared to base line conditions. Thus, it was concluded that the lagoons were not leaking and ground-water contamination was not taking place. It was only after new monitoring wells were designed and installed under state guidance that the problem was discovered. Further detailed study revealed that about 200 million gallons of contaminated ground water, with zinc and chromium concentrations of up to 50 and 150 mg/l respectively, underlie the immediate area of the property. [22)]

The situation is illustrated in Figure 27. Wells A and B represent the early monitoring wells that were improperly screened below the sand and clay zone. Well C represents the wells drilled under state guidance, which indicated there was a problem, and Wells D-1, D-2, and D-3 represent wells drilled during the detailed investigation which helped define the areal extent of the contaminated ground-water body.

Thus, locating pollutants in the ground-water system is a complicated matter. Even after contamination is indicated, defining the problem calls for use of all the various techniques available to the investigator.

The second problem with regard to monitoring is the difficulty in keeping track of quality of water from the large number of public supply, industrial, and domestic wells in the region. The widespread use of ground water was discussed in an earlier section. However, it is interesting to note some of the results of personal interviews with representatives from the various state agencies charged with health and water pollution matters.

In none of the 11 states of the project area are accurate

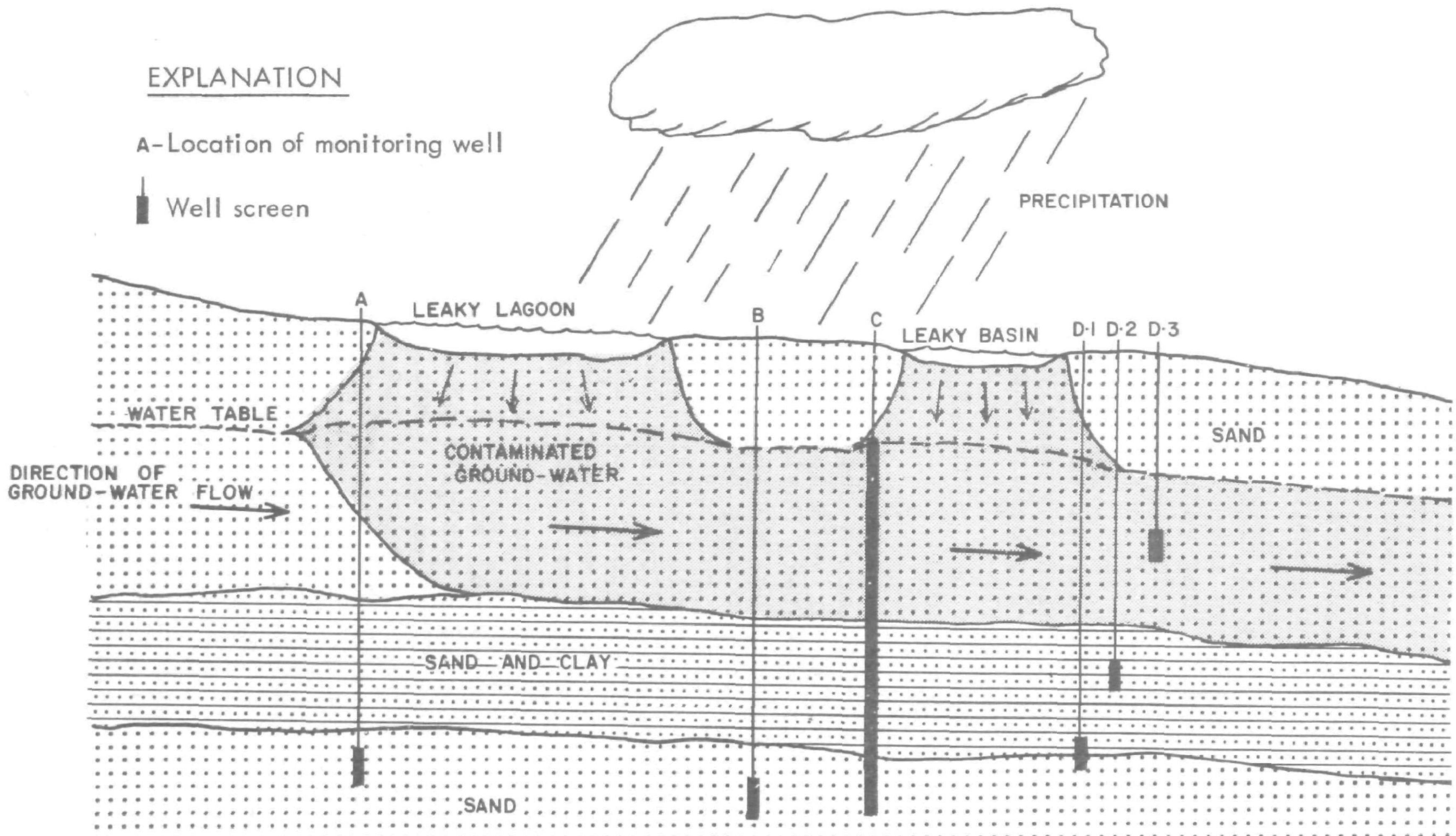

Figure 27. Movement of contaminated ground water beneath leaky lagoons and basins

figures available on the number of wells drilled each year, how many are in use, or what proportion are abandoned. Even in those states where permits are required for new well construction, such as New Jersey and Maryland, the estimate is that applications for permits are received for only about half of the wells drilled. New Jersey presently has about 100,000 well permits on file and, for the period July 1969 to July 1973, Maryland issued permits for more than 31,351 wells. During this four-year period, the number of applications per year almost doubled in Maryland. In addition to the tremendous number of individual ground-water sources, only for a relatively small percentage of new wells is the water analyzed. Exceptions to this, of course, are public water-supply wells which invariably must be approved by some type of health authority before they are put into service. However, domestic wells and those used by industry for drinking-water purposes do not normally fall within the authority of public health agencies.

Many state and local agencies offer the free service of running analyses for selected chemical constituents and bacteria in water from private sources when the sample is brought in on a voluntary basis. In fact, many of the state laboratories report that their personnel and facilities are sorely taxed trying to keep up with this activity. Nevertheless, again only a relatively small percentage of the wells drilled are sampled initially, and, just as critical, even fewer are sampled on a periodic basis. In a detailed investigation of the quality of water from domestic wells in York County, Maine, it was found that 461 of the 511 supplies sampled (90 percent) had never been inspected by a health agency. [23)]

In some states and local areas, there has been a growing trend toward requiring analysis of new private well-water supplies and certification by a health agency before the well can be put into service in the home or factory. This trend undoubtedly will continue but there still will be a need to sample wells that have been in service for many years, to conduct periodic analyses of water from new wells, and to locate the large number of unreported wells installed each year in the region.

Even the present effort given to public water-supply wells may not be enough to guard against the threat of possible use of contaminated water. Again, the number of individual sources is startling. For example, the Connecticut Health Department must inspect and monitor 639 wells and springs used for public-supply purposes. [24)]

The need for continuously monitoring such supplies on a periodic basis also relates to the manner in which a contaminant can migrate through the ground-water system. As explained earlier, a body of highly contaminated fluid can move as a distinct plume and can advance as a front through a particular aquifer. Thus, water from a pumping well can be of safe quality for many years and then become adversely affected over a relatively short period of time when an advancing front of poor-quality water reaches the well. The advancing front characteristic of salt-water encroachment in heavily pumped coastal areas has been well documented, and the drastic change in water quality that can occur by movement of such a front into a well field is illustrated in Figure 28. In this case, periodic chloride analyses of water from a well being used in the Cape May City area of New Jersey showed very little change from late 1945 to late 1950. Then within a matter of weeks, after lateral encroachment of a salt-water front reached the well, chloride concentration began to rise significantly and continued on an upward trend for the duration of the record shown. Horizontal movement of such fronts in coastal plain aquifers has been measured at rates of a few feet to more than 100 feet per year.

In Endicott, New York, high counts of coliform bacteria suddenly showed up in a million-gallon-per-day municipal well after 19 years of trouble-free operation. [26)] Excavation of the bed of the Susquehanna River, which was locally contaminated by sewage, appears to be responsible for the problem. Higher infiltration rates caused by the excavation allowed bacteria to enter the sand and gravel aquifer tapped by the well, and the bacteria traveled 180 feet to contaminate this ground-water source. Routine weekly water samples revealed the problem, and the well was immediately taken out of service.

Unfortunately, such frequent sampling of public water supplies is not universal. A recent survey by the Comptroller General of the United States of federal and state programs needed to insure purity of drinking water included three of the states in the northeast study region: Maryland, Massachusetts, and Vermont. [27)] A review of the most recent chemical analyses on file for two of these states revealed that for Maryland, 27 percent and for Vermont, 49 percent were more than one year old. In addition, only in Maryland were public health officials satisfied that the frequency of surveys of water supplies is adequate enough to detect potential sanitary problems.

Some idea of the wide variety of potential sources of ground-water pollution can be gained from the compilation given in

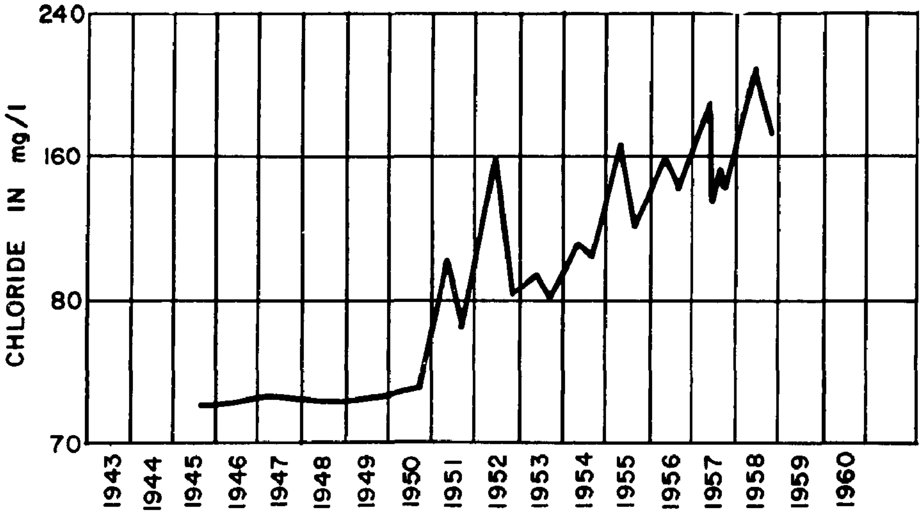

Figure 28. Long-term chloride fluctuation in a well tapping the Cohansey Sand in the Cape May City area, New Jersey [25]

Table 25, which is based on an analysis of actual reported cases of ground-water contamination inventoried during the northeast investigation. Representative examples of the various categories listed were obtained from public agencies involved in health and environmental matters, from well-drilling contractors, from private organizations such as consulting firms and business associations, and from literature sources. It can be seen that many activities of man can lead to degradation of ground-water quality. Monitoring of the potential source, either by means of accurate measurement of losses of fluid and soluble material to the ground-water system or through the installation of enough wells for periodic water-quality sampling, is an almost insurmountable task. Even inventorying the location of potential sources of contamination is a major problem for regulatory agencies.

Although no list could contain all causes of subsurface pollution, Table 25 does include the key sources, and an attempt has been made to rank them according to their importance and to assess the degree of environmental hazard. It is interesting to note that some items listed, such as septic tanks and cesspools, are a major problem throughout the entire region whereas others vary in importance from area to area. For example, many public officials in the northern and central New England States feel that salts from highway deicing are the most significant factor in ground-water quality degradation. In New York and Connecticut, the major factor tends to be high densities of septic tanks in new housing developments. Landfills and industrial-waste lagoons, pits and basins appear to be receiving the most attention in New Jersey, Maryland, and Delaware. Finally, in Pennsylvania, major emphasis is being placed on permitting programs for solid waste, coal refuse disposal, surface impoundments, and spray irrigation.

The third column in Table 25 is an estimate for the region as a whole of the rate of new occurrences for each of the sources listed. Each estimate is based on an evaluation of such factors as awareness of the particular type of problem; the predicted degree of activity creating incidences of contamination; anticipated staffing of federal, state and local environmental programs; laws, rules, and regulations in effect or proposed; and the level of technology available to prevent future problems.

The abundance of septic tanks and cesspools is a good illustration of the difficulty in monitoring the source. Table 26 lists the populations not served by central sewer systems on a state-by-state basis. These statistics would indicate that there are millions of individual septic tanks and cess-

Table 25. PRINCIPAL SOURCES OF GROUND-WATER CONTAMINATION AND THEIR RELATIVE IMPACT IN THE NORTHEAST

Sources	Relative importance to region [a]	Typical size of area affected [b]	Estimated future trend in rate of new occurrences [c]
Septic tanks and cesspools	I	II	I
Buried pipelines and storage tanks	I	II	II
Application and storage of highway deicing salts	I	II	II
Landfills	I	III	I
Surface impoundments	I	III	III
Spills and surface discharge	I	III	II
Mining activity	II	II	II
Petroleum exploration and development	II	II	II
Salt-water intrusion	III	I	III
River infiltration	III	IV	I
Underground storage and artificial recharge of waste water	III	III	I
Water wells	III	IV	II
Agricultural activities	III	II	III

a) I - High
II - Moderate
III - Low

b) I - Regional
II - Point source but can be regional in nature due to high density of individual occurrences
III - Can affect adjacent properties
IV - Effects usually contained within the boundaries of one property

c) I - Increase
II - No significant change
III - Decrease

Table 26. ESTIMATED POPULATION SERVED BY SEPTIC TANKS IN 1968, BY STATE. [28)]

State	Estimated population served	Percent of total population
Connecticut	1,344,845	46
Delaware	131,390	26
Maine	413,885	43
Maryland	2,049,395	57
Massachusetts	1,661,990	31
New Jersey	1,131,290	17
New Hampshire	392,200	57
New York	2,918,640	17
Pennsylvania	1,435,929	13
Rhode Island	331,975	38
Vermont	211,700	51
Total:	12,023,239	22.5

pools, each discharging domestic wastes into the subsurface environment. In addition, there are hundreds of areas where their density is great enough to have caused significant rises in nitrate concentration in ground water, created problems of detergent in well supplies, or threatened health due to migration of bacteria and viruses into poorly constructed and improperly located wells. Also, migration of nitrate from aquifers into surface water is most important because nitrogen constraints for many streams are more severe than drinking water standards.

Examples that are typical of unsanitary conditions experienced by many domestic well owners, mostly in the rural portions of the region, are as follows:

*In a six-year survey (1955-1960), personnel of the Rensselaer County, New York, Health Department carried out sanitary surveys of 2,100 private dwellings served by on-site water-well supplies. 29) On the average, 38 percent of the water samples collected showed the presence of contamination, and 42 percent of the wells were ruled improperly constructed, protected, or located. At least 25 percent of the home owners that were informed of an unsanitary condition in their water-supply system made corrections based on the Health Department recommendations. In 1970, County personnel surveyed 94 wells in one semi-rural area and found that 49 percent were producing water of unsanitary quality and 30 percent more of questionable quality. 30)

*The Connecticut State Department of Health surveyed individual wells in one rural town which has neither a public water supply nor a central sewer system. Based primarily on coliform count and supported by data on concentrations of nitrogen compounds, it was concluded that 30 percent of the 50 wells sampled were producing water that was probably unsafe for drinking. 31)

*In the York County, Maine, investigation mentioned previously, 17 percent of the 462 water wells sampled were considered by the investigators to be contaminated. Well construction appeared to be the key factor because water from 30 percent of the dug wells was found to be contaminated as compared to four percent for driven and seven percent for drilled wells. 23)

*More than half of 40 wells sampled in a rural area of Pennsylvania underlain by carbonate rock were found to yield water containing "excessive bacteria". 16)

Community landfills and open dumps are also more numerous in the northeast than generally realized. Literally thousands of sites exist where domestic refuse, industrial solid and liquid waste, and septic tank cleanings have been deposited for many years. Investigations have shown that landfills are an almost universal source of ground-water contamination, yet less than one percent are monitored by periodic sampling of wells specifically drilled to watch over possible changes in ground-water quality. This is true even though surveys indicate that 15 to more than 20 percent of the operators of community landfills have reported surface drainage and leaching problems, and that the lowest part of the fill is in the water table, an excellent indication that subsurface contamination is occurring. 32) Effects on ground-water quality include increased concentrations of such constituents as chloride, iron, manganese, hardness, and total dissolved solids. Where solid-waste sites have also received industrial liquids and sludges, the presence of heavy metals in the leachate has been observed. Connecticut estimates that in 1972, 33 million gallons of industrial liquid and sludge wastes were probably deposited in municipal landfills in that state, of which 7.5 million gallons were oils and hydrocarbons and more than 3.5 million were solvents. 33) Until recently, only in Pennsylvania was the installation of monitoring wells mandatory at landfills. 34) Now, however, most of the other states in the region are beginning to call for monitoring at new and old landfills, especially those suspected of causing ground-water contamination.

Two other important examples of sources from Table 25 that are most difficult to monitor are salts from highway deicing and leaks from buried pipes and storage tanks. During the winter season of 1966-67, almost two million tons of sodium chloride and 70,000 tons of calcium chloride were spread on highways in the 11 northeast states. 35) Monitoring the thousands of miles of roadways to locate areas where melt water has carried these highly soluble substances to the water table and has significantly affected ground-water quality is physically and economically impossible. A similar situation exists with regard to the length and number of buried pipelines and storage tanks that may be leaking toxic or hazardous liquids into the ground. There are no strict regulations governing the monitoring of storage tanks as to maintenance or replacement. Pennsylvania alone estimates that 2,600 new or replacement subsurface storage tanks are buried in the ground each year. 36) Most are probably used until they fail, which means the liquid they contained was lost to the subsurface.

Another problem in monitoring is the great variety of inorganic metals, salts, acids or bases, synthetic organics, flammables and other compounds produced each year in the northeast. Much of this material is toxic and finds its way into industrial waste streams. It has been pointed out that of 496 organic chemicals considered likely to be found in water, only 66 have been positively identified. 37) Hazardous substances such as arsenic, cadmium, chromium, chlorinated hydrocarbons, cyanides, lead, mercury, copper, and zinc are widely used in many industrial activities including metallurgy; paint, rubber, and paper manufacturing; and the production of batteries, pharmaceuticals, and textiles.

Unfortunately, many toxic substances are not included in normal analyses conducted on water-supply sources. In fact, in the 11 northeast states, analyses for some of the hazardous elements such as barium, selenium, and silver, included in the U. S. Public Health Service Drinking Water Standards, 1962, are not usually required for a ground-water source to be approved, nor are they often included in routine analyses unless contamination is suspected. 38) In the Comptroller General survey mentioned previously, Massachusetts did not make analyses of water from public supplies for any of the nine chemicals included in the Public Health Service mandatory standards, except for those supplies serving interstate carriers. 27) Vermont did not run analyses for 7 of the 20 chemicals included in the mandatory and recommended standards. Interviews with public health personnel in the region did indicate that more effort is being made to determine the possible presence of toxic substances, and that there is an overall trend toward more complete analyses of drinking water. However, again this is difficult to accomplish due to limitations of budget, staff, and laboratory facilities.

It is interesting to note that the vast majority of the hundreds of ground-water contamination case histories inventoried in this investigation came to the attention of authorities because of complaints of taste or odor, noticeable effects on surface waters or vegetation, or through the investigation of an accident such as a ruptured storage tank or a spill of hazardous material. Few were uncovered in the course of routine analysis of the water itself. Where hazardous substances were involved, for example, in those cases involving high concentrations of arsenic, hexavalent chromium, cyanide, or lead, it was a change in the non-toxic constituents which are normally determined, such as iron, chloride, and hardness, that led to more complete analysis of the water from the affected source. Only after the more detailed testing was the presence of the toxic substance determined.

Several case histories in Connecticut illustrate these points. A family supplied by a domestic well suffered mysterious loss of hair.[31] Analysis of routine constituents in the well water revealed no indicator that could be traced as a cause of the phenomenon. It was only after a test for thallium, rarely included in water analyses, was conducted that the source of the problem was determined. Heavy use of thallium-bearing agricultural sprays in the area had contaminated the aquifer tapped by the domestic well.

In another case, presence of a chlorinated hydrocarbon was only detected in a high school well because of the foul taste and odor associated with this substance.[31] The source was the dumping of waste solvents on a neighboring industrial property. Finally, during a routine pumping test to determine the yield of an industrial well that had been in service for a number of years, it was noticed that the water being pumped to waste during the test had a distinct yellow color.[39] This had not been observed before because chemical analyses of ground water had not been run for many years and the water from this well was mixed with water from other sources in the industrial plant. Analysis showed that the color was caused by the presence of chromates in concentrations of as much as 26 mg/l. The source of the contaminated water was leakage out of the bed of a lagoon, about 1,000 feet away, receiving wastes from a metal-plating company.

Technical and Economic Difficulties

One particular aspect of ground-water contamination that makes it quite different from river pollution, and in many ways a more difficult problem to solve, is the long time factor required for decay, adsorption, or dispersion of the contaminant in the ground-water system even if the source of contamination is removed. Correcting a situation causing ground-water contamination, such as lining a leaky basin into which a liquid industrial waste has been discharged, will prevent an increase in the volume of the highly mineralized fluid arriving at the water table but will not result in an end to the problem itself. Because the polluted ground-water body normally moves and disperses slowly, and is little affected by dilution from the recharge of or mixing with unaffected water, contaminants in ground water tend to be reduced in concentration over a period usually measured in years and even decades. In fact, long after a source of pollution has been removed, the contaminated ground-water body actually can expand in areal extent and can travel significant distances before it disperses.

Few studies have been carried out that would define in detail the degree to which contaminants will become attenuated with time and distance traveled after the source of pollution has been removed. One recent investigation by George F. Pinder of Princeton University applies a mathematical model capable of predicting the transient behavior of a plume of contaminated ground water over a wide range of field conditions. [40] Use was made of the chromium contamination case on Long Island referred to in a previous section. [11] In this situation, the point of discharge for the 4,300 foot long plume of contaminated ground water is a creek, which drains the water-table aquifer in the area. Pinder has computed that ground-water contamination of the creek would continue for seven years after disposal of the pollutant to the land surface is ended. Ground-water velocity was computed to average 1.4 ft/day.

Within the northeast region, there are several widely used methods for combating contamination of ground water after it occurs. The first step, once the problem has been discovered, is an attempt to prevent the activity from continuing to degrade water quality, in other words, eliminating the source as quickly as possible. For example, a specific activity such as the discharge of industrial wastes into a limestone sinkhole can be ended immediately if action is brought to bear by a public agency equipped with evidence that a well supply has been rendered unfit or is threatened because of the industry's disposal method. A storage tank can be pumped dry and taken out of service if it is traced as the source of a gasoline leak that has affected ground-water quality in the area.

However, it is not always possible to immediately end some types of activities that contribute to ground-water contamination. For example, because no adequate substitute has been found for highway deicing salts, the process is continued even in areas where wells have been shown to be adversely affected. In some communities, the quantity of salts normally used has been reduced, but this is not an ultimate solution to the problem. In the case of municipal landfills, it is a difficult and time consuming project to find a substitute site for the dumping of refuse even though an existing site is found to be a source of ground-water contamination. Additional water-quality degradation of an aquifer from septic tank wastes can be halted by the installation of collecting sewers, but again planning and implementation of such a system can be slowed drastically by economic and political considerations.

Of course, if a well supply has been affected by a pollutant, especially if the substance is toxic, the other initial step taken in combating the problem is the abandonment of the well or wells and replacement with a new source, if available. In fact, based on the inventory of case histories in the region, the abatement procedure often ends with the abandonment of the water-supply source or the physical treatment of the water pumped in order to reduce the concentration of the pollutant to an acceptable level. This course of action is more or less typical due to the technical difficulties inherent in correcting the souurce of some types of ground-water contamination and the physical and economic problems involved in controlling or removing the pollutant.

Nevertheless, there are two basic approaches that have been used in the region to control the spread of or to clean up contaminated ground water. The first is containment and the second is actual removal of the pollutant.

Containment involves the use of methods to protect against the spread of degradation of water quality within the aquifer already affected, to other aquifers that might be affected, or to surface water bodies into which the contaminated ground water might discharge. It is an approach often used to protect existing ground-water and surface-water users but does not help well owners whose supplies are already damaged, nor does it fully restore water quality in the aquifer to its natural state within what might be considered a reasonable length of time.

An excellent example of containment is the widespread effort being given to salt-water encroachment problems in the region. This form of ground-water contamination was one of the earliest recognized in the northeast, and such states as New York and New Jersey began to control, many years ago, diversion of ground water in critical areas in order to impede the movement of saline water inland in heavily pumped aquifers. The strict control of pumping patterns through the enforcement of state permit systems for use of ground-water has been very successful in slowing down and, in most cases, ending the threat of additional well supplies being lost because of salt-water encroachment. However, areas already affected before such controls were initiated have not fully recovered because of the slow movement of the salt-water front.

This slow rate of recovery is illustrated by the salt-water encroachment problem experienced in Kings County, New York, during the period 1903 to 1947.[41)] Salt water from estuaries and embayments bordering the County had moved several miles inland and had contaminated numerous public supply and industrial wells. The problem had been created by a severe decline in ground-water levels caused by excessive pumping from both the water-table and deeper confined aquifers, the wasting to sewers of all water from public supply and many industrial wells, and a substantial decrease in natural recharge from precipitation owing to extensive paving of aquifer intake areas with streets and buildings. A severe cut back in ground-water pumpage took place in 1947 because of condemnation of a private water company, which had supplied as much as 27 million gallons per day of ground water to residents in central Kings County. This factor combined with such conservation measures as the passage of legislation that required the artificial recharge of water used for air-conditioning and cooling, eventually reversed hydraulic gradients in most of the County. Further encroachment has been halted, but it is estimated that 30 to 40 years may be required to flush out the remaining salt water that intruded the aquifers.

Containment of leakage from industrial waste lagoons, pits, and basins at a site in New Jersey is an example of a case in which it was found that removal of the pollutants from the aquifer would not be feasible because of the slow movement of ground water in the affected aquifer, even under pumping conditions.[42)] In this situation, ground water containing extremely high concentrations of heavy metals, including chromium, zinc, and copper, is confined to a 30-foot thick zone in the water-table aquifer. The estimated several hundred million gallons of contaminated fluid was threatening to leak into deeper heavily pumped aquifers in the area and also was slowly moving toward a tributary to the Delaware River. Discharge of the pollutants into the surface stream would have had an adverse effect on its water quality. A series of shallow wells pumping at a rate greater than natural recharge to, and discharge from, the water-table aquifer were installed between the source of contamination and the stream to prevent the pollutants from reaching the surface-water body. Also, pumping the wells has lowered the water level in the shallow deposits so that downward movement of ground water to deeper aquifers is impeded. Some of the contaminated water is being removed and is being treated before discharge to waste, but the well system is primarily acting as a containment system. The aquifer will remain contaminated in the vicinity of the industrial site for many years, even though the lagoons, pits, and basins that were the original source of the problem have been lined with concrete and no longer leak.

Another form of containment and its associated problems is demonstrated by the case of a landfill pollution problem in southern Connecticut located adjacent to Long Island Sound.[43] Highly mineralized ground water formed by the leaching of soluble substances from municipal and industrial refuse contained in the landfill is moving toward and discharging into the Sound in the vicinity of a beach heavily used for swimming. The flow of subsurface water is being influenced by an abnormally high water table that has been formed within the landfill.

In order to prevent deterioration of Long Island Sound water, further discharge of the contaminated ground water should be prevented. Installing a system of pumping wells to remove the leachate or to intercept it before it reaches the Sound is not feasible because of the fine-grained nature of the sediments underlying the site. The only reasonable approach to the solution of the problem appears to be sealing off the surface of the landfill to prevent further infiltration of rain water. In this way, the production of new leachate would be reduced; the abnormally high water table would drop; and the rate of discharge of contaminated ground water to the Sound would become insignificant. However, the body of water already contaminated and contained within the aquifer will remain beneath the site for many decades with such constituents as iron and manganese considerably above the concentrations recommended for potable waters. Computations based on detailed drilling and water-level data show ground water to be moving at a maximum rate of only 0.25 foot per day, and that contaminated water underlies an area in excess of 75 acres. Of course, sealing the surface of the landfill will require gas venting. Also, periodic maintenance of the seal itself will be needed to prevent deterioration and to counteract subsidence and erosion.

Actual removal of the pollutants from the ground-water reservoir has been attempted at a number of locations in the northeast but is not practiced on a broad scale again because of technical and economic considerations. Use of wells drilled specifically for the purpose of pumping out the contaminated fluid is the most common approach to removal. The water is then subjected to treatment on-site, discharged to a sewer or nearby surface-water body, or collected for reprocessing and reuse. Existing supply wells, to which the polluted water has migrated, have also been pumped in an attempt to reduce the volume or concentration of the pollutant. A third approach has been the construction of surface drains and ditches in order to skim the pollutant off the water table.

Generally, removal has been applied only in those cases where ground-water contamination represents a severe health or economic hazard. The presence of hydrocarbons in the ground-water system is an example of a severe hazard especially in urbanized or industrialized areas where there is a good potential for loss of life and damage to property unless as much as possible of the oil or gasoline is removed. Another example is the discovery of a highly toxic substance in ground water, such as arsenic or mercury, which is an obvious hazard to health if the contaminated fluid were to be left in the ground to perhaps migrate to a supply well or surface stream. Attempts also have been made to remove contaminated ground water if there is a distinct economic advantage, such as recovery of an affected community or industrial well that is vital to the water-supply system or protection of an important aquifer.

One of the most difficult types of removal operation is that dealing with hydrocarbons. Here, the problem involves a two fluid system due to the light density and low solubility of the hydrocarbon. The pollutant floats and migrates on top of the water table. Drawing down water levels and inducing the fluid to migrate toward a pumping well will trap only a portion of the hydrocarbon. Ultimately, as the lens thins, less and less of the substance is removed. Thus, in addition to pumping wells, use has been made of ditches and trenches to skim oil off the water table, biological processes to break down gasoline in the ground, and water-flooding techniques to drive solvents and other hydrocarbons to central collection points, all with limited success. In fact, when raw gasoline was detected in shallow deposits beneath a business section in Queens County, New York, and alternative methods of removal had failed, an entire city block was excavated from curb to curb in order to physically expose the contaminated sand beds so that the gasoline could be removed. [44] Special non-ferrous tools were employed in the digging to eliminate the danger of sparks.

Even when a pollutant can be successfully removed from an aquifer, the time period involved and the quantity of water pumped is usually considerable. For example, two public supply wells about 100 feet deep tapping a limestone aquifer in southeastern Pennsylvania were contaminated by wastes from a tool-plating factory, that had been discharging into a sinkhole three-quarters of a mile away. [45] Concentrations of hexavalent chromium in the water from the wells was 0.35 mg/l when the problem was discovered. It took a period of 2-1/2 years, pumping at a rate of more than one-half million gallons per day, to reduce the concentration of the contaminant to a level of 0.02 mg/l. Use of the sinkhole by the factory had been halted immediately. The water pumped from the wells during the removal operation is treated before being discharged to a stream.

In another case, along the Delaware River in New Jersey, an industry is pumping at an average rate of 4,025 gallons per minute in an attempt to remove from a shallow aquifer, pollutants that were moving toward existing wells.[14] The withdrawn contaminated water is used for process and cooling before being treated and discharged to the Delaware River. A detailed monitoring system is being employed to determine how successfully the system is working and the degree to which the pumped water will require treatment.

Any discussion of the problems associated with the control and correction of existing ground-water contamination problems would not be complete without consideration of the high costs involved. The best method to illustrate the important impact of this factor is to explore a number of case histories that have come to light during the northeast investigation.

As indicated in Table 25, landfills of municipal and industrial wastes rank high in the number of significant occurrences of ground-water contamination in the region. In one case in southeastern New York State, litigation was brought against a county by the U. S. Attorney because the operation of a regional solid waste landfill did not meet the requirements of the 1899 Refuse Act, which prohibits discharge of wastes without a permit into navigable interstate streams.[46] In a court action, the County was directed to define the extent of ground-water contamination problems associated with the landfill and to determine the environmental impact on the river and wetlands bordering on the landfill. The hydrologic, geologic, and biologic studies extended over a period of two years. Legal fees plus the scientific investigations amounted to more than $250,000. This figure does not include engineering design and other costs involved in completing the landfill to the satisfaction of the court or in finding, purchasing, and designing a new site for refuse disposal.

In another landfill case, in Delaware, solution of a ground-water contamination problem may cost upward of $2,000,000.[47] Leachate generated by the landfill is moving through the affected aquifer toward two large well fields, one owned by a chemical company and the other by a private water company, which has already reduced its pumpage significantly in order to slow down the movement of the contaminant. A line of high capacity wells is being installed for the capture of the leachate, which will require treatment after removal from the ground. The surface of the landfill may be regraded in an attempt to prevent infiltration of rainwater into the refuse. The mass of solid waste measures 1.0 mile by 0.1 mile by 30 feet thick. The site had been abandoned for four years before contamination was detected in a private well 650 feet from the landfill. 48)

In a third case, located in western Connecticut, a landfill had been operated by a town for many years in what was considered a remote area. As population increased in this suburb, new housing developments encroached on the landfill site. The town has no central water-supply system, and homes are supplied by domestic wells. Ultimately, about 50 such wells for a new housing development were drilled adjacent to the landfill into an existing zone of contaminated ground water contained in the crystalline bedrock aquifer on which te landfill is situated. The aquifer had been contaminated over the years by leachate moving through the refuse and into the water-bearing bedrock fractures tapped by the new wells.

Immediate containment or removal of the pollutants so that the home owners can continue using their wells does not appear to be technically feasible. Instead, the town must develop a community supply off-site and pipe potable water to the affected homes. The capital cost alone for this utility is estimated to be about $500,000 with an annual carrying cost of $55,000. 49)

Highway deicing salts are another widespread source of contamination in the northeast and the yearly rate of increase in the number of well supplies affected is rising. In several New England States, the problem has become routine enough to actually budget each year an amount of money to be spent in replacing wells adversely affected by highway salts. For example, New Hampshire allotted $100,000 in 1973 to the Department of Public Works and Highways to provide relief to land owners who had their water supplies damaged by state operations of all types. Most of this money has been used to drill replacement wells for road-salt damaged water supplies. The 1974 budget is estimated at $200,000. 50) Maine has a system similar to New Hampshire's and spent more than $46,000 during the fiscal year July 1, 1971 to June 30, 1972 settling claims almost exclusively arising out of wells that had been contaminated by highway salts. 51)

Finally, some costs involved in solving ground-water contamination problems are related to treating the affected water in order to reduce the concentration of the substance to acceptable levels. Water supplies in some portions of Nassau County, New York, exceed the U. S. Public Health limit for nitrate content (as N) of 10 mg/l. This regional ground-water contamination problem has been related primarily to septic tank and cesspool effluent, fertilizers, and animal wastes. In one situation, the Garden City Park Water District was required to reduce its water-supply capacity by 60 percent because of the forced shutdown of nitrate contaminated wells. Blending of water from different wells and extending existing wells into deeper aquifers were ruled out as possible solutions to the problem, and the District was forced to explore the possibility of treatment.

After considerable experimentation and research, an ion-exchange process, originally developed to demineralize industrial process water, was recommended. A treatment system was devised and the plant constructed at a total cost of about $400,000. An average of 1,200 gallons per minute of water containing more than 20 mg/l nitrate (as N) is handled in the treatment system.[52]

Summary

The various factors discussed above should indicate the cause for concern regarding ground-water contamination and the need for more research, control, and education to help prevent new occurrences and to aid in correcting existing problems. This investigation revealed the fortunate circumstance that there are a few dedicated technicians on different levels of government in each of the states working toward educating the public on the importance of protecting ground-water quality, in addition to developing guidelines and manuals to prevent practices that might adversely affect this underground water source. However, activities involved in the protection and monitoring of ground-water quality, with a few notable exceptions that will be discussed later in this report, are too splintered among various agencies to be effective. In addition, the agencies are hindered by lack of sufficient budget to staff properly and to carry out the functions necessary for ground-water management programs to be successful.

In the following portions of this section, key sources of contamination will be explored in greater detail. By this means, it is hoped that the principal problem areas, which require the greatest effort, can be illustrated. A review of case histories on ground-water quality degradation provides the best means for understanding the nature of the problem in the northeast. In this regard, selected instances of contamination are tabulated. Where possible, locations and references are provided for each of the cases included. However, where future litigation may be involved, for example, and the data shown does not appear in the literature, the location and reference may not be listed in order to respect the confidential nature of the information.

SEPTIC TANKS AND CESSPOOLS

Certainly one of the most significant sources of groundwater contamination in the northeast is discharge from septic tanks. A large number of cesspools are still in use, and privies or direct discharges to surface waters can still be found in some rural areas. However, the septic-tank, tile-field system has been almost universally adopted throughout the region to provide a means for disposing of wastes from homes, stores, laundries, small office buildings, hospitals, and industries in areas where community sewer systems are not available. The major growth in septic-tank use has taken place since the second World War due to the explosive development of suburban areas on the fringes of the major cities.

In the 11 states of the study region, approximately 12 million people or 23 percent of the total population is served by individual home waste water treatment systems. 28) Assuming an average domestic water-use of 40 to 80 gallons per day per capita, as much as one-half to one billion gallons of raw sewage is discharged from residences directly into the subsurface each day in the study region. To this figure must be added the millions of gallons per day discharged to the ground from commercial and industrial septic tanks.

The complete septic-tank and tile-field system consists of three basic components. The first is the septic tank itself, which is a water tight, non-corrosive, and covered receptacle designed to remove solids by settlement and to trap and store scum and sludge. The second is the distribution box, which is needed to insure equal distribution of effluent to the several lateral lines of the tile field. The third component is the soil absorption system or tile-field. This consists of a series of pipes, usually made of perforated orangeburg fiber or plastic material, the purpose of which is to distribute as evenly as possible the sewage effluent over an area of soil large enough to absorb it. The distribution lines are normally laid in trenches, backfilled with filter material consisting of washed gravel, crushed stone, or slag. Figure 29 shows the layout of a typical septic-tank, soil-absorption system.

Another device commonly used in conjunction with or instead of the septic tank system for discharging effluent into the soil is the cesspool. It is a large buried chamber, which

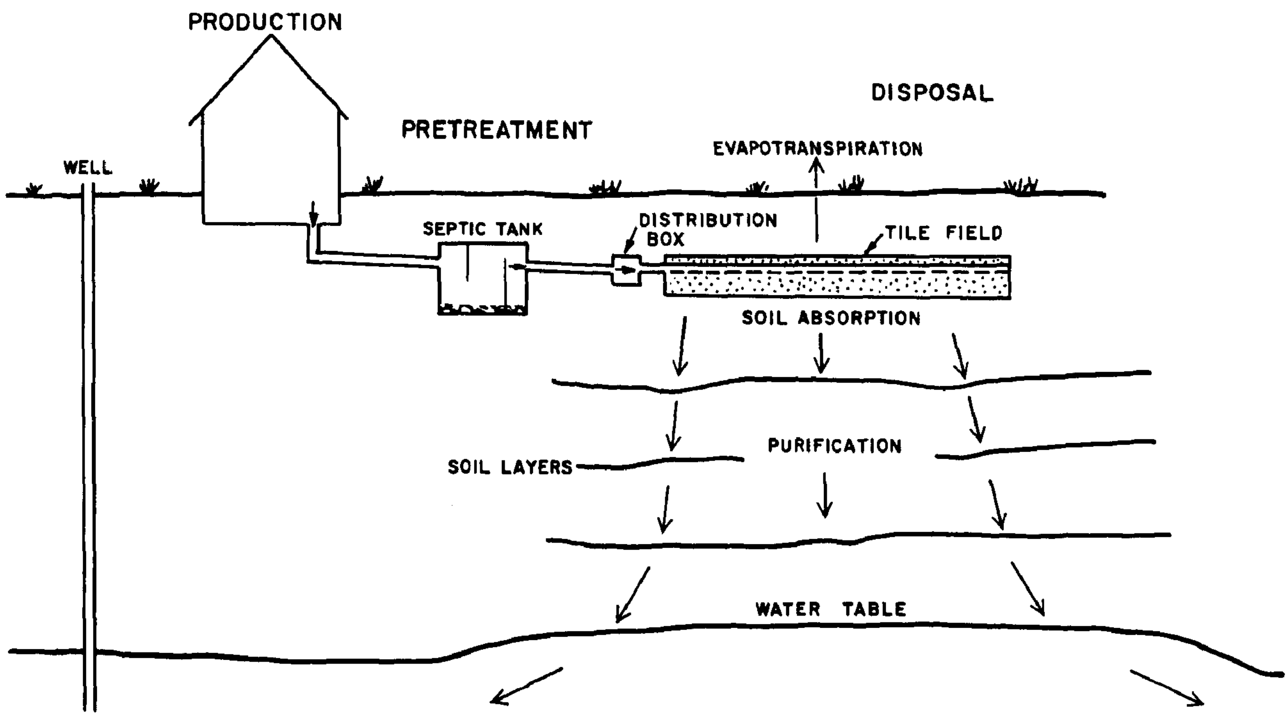

Figure 29. Disposal of household wastes through a conventional septic tank-soil absorption system [53)]

is walled up with a porous material such as precast perforated concrete rings or concrete blocks. The size of the chamber varies according to hydraulic loading and other design considerations.

It is a generally accepted fact that as much as 300 mg/l of total dissolved solids are added to water by domestic use, and, thus, the effluent from septic tanks can increase the concentration of minerals in ground water. Table 27 shows the range of mineral pickup in domestic sewage. Under normal conditions of soil pH, efficient removal of phosphates can take place, but chlorides, nitrates, sulfates, and bicarbonates can enter and move freely within a ground-water body. Bacteria and viruses are normally removed by the soil system, but, under conditions favorable for their survival, can reach the water table and can travel significant distances through an aquifer. Some other pollutants that have been found associated with septic tanks include synthetic detergents, excessive chlorides from water softener regeneration, and a number of toxic and non-toxic constituents in special cases where industrial wastes have been discharged to a septic tank.

The percolation test is used as the principal deciding factor on whether or not septic tanks would be acceptable for particular sites. This test measures the rate of decline of the level of clear water in a series of wetted holes. The faster the water dissapates in the hole, the greater the assumed performance of the proposed septic system. However, there are a number of limitations on this method. Clear water and sewage effluent can react quite differently in soil. More important to ground-water contamination, coarse-grained deposits that will perform the best in percolation tests can be the least effective in removing bacteria and nutrients. Finally, reliance on percolation tests will not indicate long-term effects on ground-water quality from various densities of septic tank installations.

Case Histories

Inadequate experience and lack of sound scientific planning on the use of septic tank disposal systems have led to a number of regional ground-water quality problems in the northeast. In addition to regional problems, there are individual cases of water from domestic wells being contaminated by on-site waste disposal systems. This latter number probably ranks in the thousands. Discussions on ground-water contamination held during this investigation with county and municipal health authorities throughout the region invariably included a number of references to private

Table 27. NORMAL RANGE OF MINERAL PICKUP IN DOMESTIC SEWAGE.[54]

Mineral	Mineral range (mg/l)
Dissolved solids	100 - 300
Boron (B)	0.1 - 0.4
Sodium (Na)	40 - 70
Potassium (K)	7 - 15
Magnesium (Mg)	3 - 6
Calcium (Ca)	6 - 16
Total Nitrogen (NO_3)	20 - 40
Phosphate (PO_4)	20 - 40
Sulfate (SO_4)	15 - 30
Chloride (Cl)	20 - 50
Alkalinity (as $CaCO_3$)	100 - 150

wells condemned because of pollutants from septic-tank effluent or because of the failure of septic-tank systems.

A few of the numerous studies carried out in the region have been selected for discussion below. They have been chosen on the basis that they might be indicative of the varied conditions under which ground-water contamination from this source can take place and that they would be most illustrative of the effects of septic tanks on ground-water quality. Unfortunately, it is difficult to prepare a table based on the results of these investigations because the methodologies used and parameters measured differ so greatly.

Eastern and Western Connecticut -

A number of studies carried out in the region point up the need for a broad technical approach for determining the feasibility of using on-site disposal systems rather than relying on an engineering analysis of whether or not the soil underlying a particular piece of property will absorb septic tank effluent at an acceptable rate. For example, Dr. Thomas L. Holzer of the University of Connecticut points out that the relatively small amount of natural ground-water recharge available in much of the crystalline rock regions of eastern and western Connecticut is the most important limiting factor to septic-tank use.[55] In nonurban portions of these areas, on-site disposal systems and individual domestic wells are located on the same lot. Only seven inches or less of the average annual precipitation of 45 inches infiltrates into the ground where crystalline rock is overlain by relatively thin glacial till. In one year, a home may easily use and discharge to the septic tank the equivalent of 3.5 inches of water spread over an acre. "As development in the nonurban areas increases, recycling of liquid waste will become an inevitable fact of life". In other words, unless low density zoning is enforced, there simply may not be enough natural recharge to counteract the build-up of nutrients in the aquifers tapped by domestic water wells.

Holzer stresses that the small capability of fractured crystalline bedrock to renovate waste water and the thinness of the overlying soil zone indicate the precariousness of development in nonurban areas unless the hydrogeology of the aquifer systems is clearly understood.

Boston Suburban Area, Massachusetts -

Another study in the Glaciated Appalachian Region of particlar interest and mentioned previously was carried out by the U. S. Geological Survey in the Ipswich and Shawsheen River Basins of Massachusetts, north of Boston. 21) The investigators concluded that "development of housing beyond the reach of the municipal sewer systems of metropolitan areas has lowered the quality of the environment in many of the (housing) developments and has created health hazards in others". Using chloride and specific conductance as tracers and correcting for highway deicing salts which are the only materials other than septic tank discharge contributing significantly to water-quality degradation, the investigators were able to develop a correlation between the relationship of housing density to residual conductance and accretion of dissolved solids in the baseflow of streams (see Figure 30).

Seventeen small drainage basins, all but one less than one square mile in area, were selected for study. All basins are served by public water supplies, but none have municipal sewer systems, and individual houses are served by on-site disposal systems. Housing density ranges from zero to 900 units per square mile. The concentration of chloride is about 50 mg/l higher in the septic tank effluent than in the tap water entering the home. Septic tank flow per house is estimated to be 200 gallons per day. The results of the investigation indicated that the reduction of mineral concentrations during travel of the septic tank effluent through the soil and bedrock aquifer is slight, and most dissolved solids from septic tank systems reach the streams.

Long Island, New York -

A comprehensive study involving intensive field research of the effects on ground-water quality of synthetic detergents and other constituents in effluent discharged by typical individual sewage disposal systems has been carried out in Long Island, New York, located in the Coastal Plain Region of the study area. 56) Six home sites were selected for observation in Nassau and Suffolk Counties, monitoring wells were installed, and the home owners agreed to fully participate in the project and cooperate in the use of several types of detergents. Based on the results of the project, which was carried out over a period of about five years, the investigators concluded that individual subsurface disposal systems provide insufficient treatment of wastes. This condition allows objectionable concentrations of biological and chemical sewage constituents to reach the water table. Septic tanks in combination with leaching dry wells and septic tanks in combination with leaching tile-fields, do not provide significant improvement in the effluent quality compared to single cesspools. The investigators also found

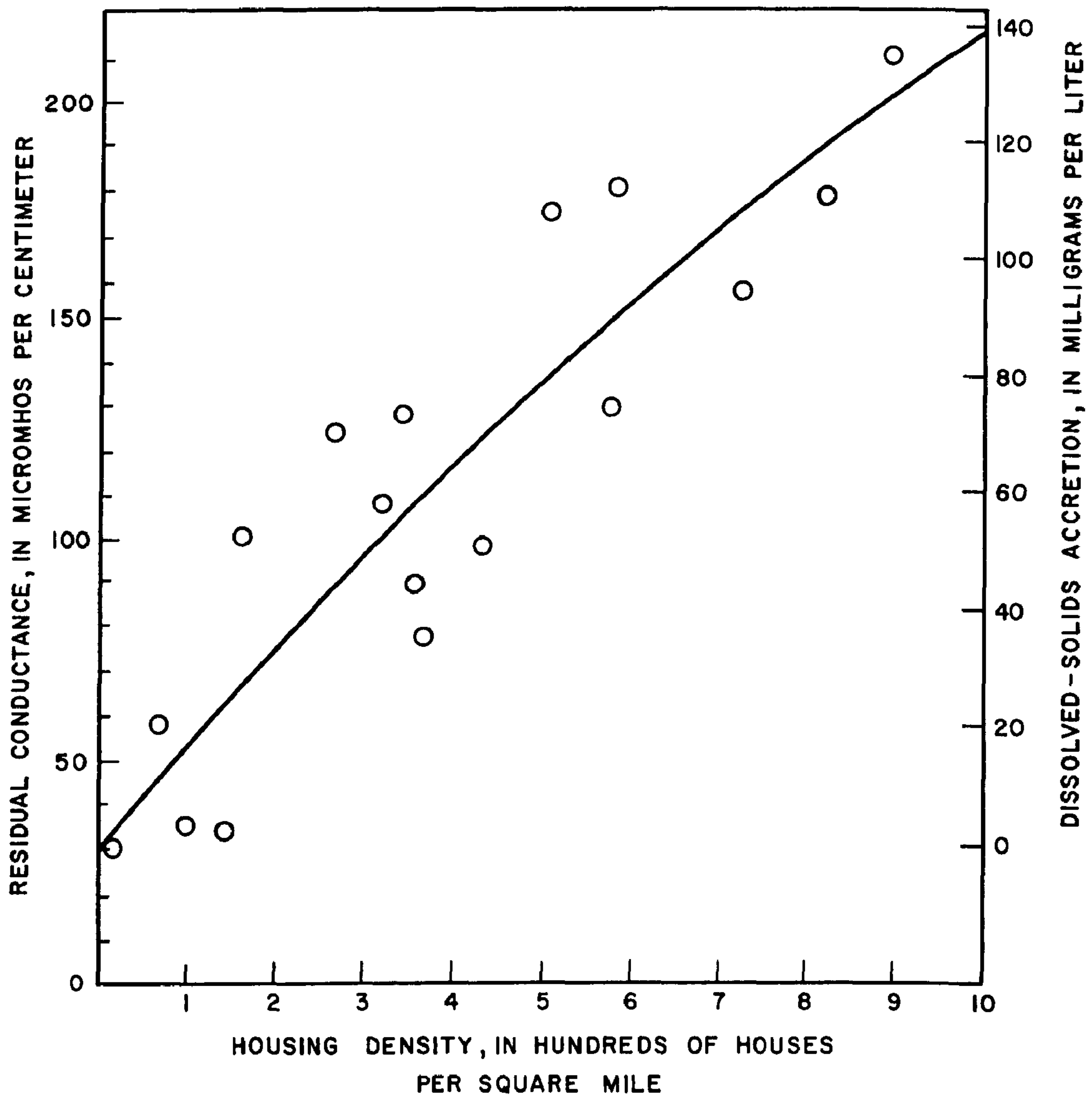

Figure 30. Relationship of housing density to residual conductance and accretion of dissolved solids in base flow of streams, Ipswich and Shawsheen river basins, Massachusetts [21)]

that viable bacteria can pass through the unsaturated soils, can reach the water table, and can travel downgradient as part of the waste stream in the aquifer.

In an investigation of nitrate in ground water and streams in southern Nassau County, the U. S. Geological Survey concluded that the two chief sources of nitrate contamination of major aquifers in a 180-square mile area were infiltrated sewage (mostly from several hundred thousand active or abandoned cesspools and septic tanks) and leachate from chemical fertilizers.[57] Nitrate content of water in the shallow glacial aquifer, expressed as nitrate ion, averaged 30 mg/l and in seven places equaled or exceeded 100 mg/l. Nitrate enriched water has also penetrated hundreds of feet into the underlying artesian unconsolidated aquifer. The nitrate content of water from 16 public supply wells screened in this deeper aquifer zone ranged from 45 to 94 mg/l.

Part of the Nassau County study area was sewered between 1952 and 1964. Nitrate content of ground-water fed streams averaged 11 and 25 mg/l in the sewered and unsewered areas respectively in 1970. The investigators concluded that improvement in the quality of chemically deteriorated ground water after construction of sanitary sewers is a slow process that may require several decades for effective natural dilution and discharge of most of the residual nitrate in the ground water. Also, a nitrate front in the deeper artesian aquifer, defined as the zone of contact between nitrate-enriched water and natural water, is moving vertically into unaffected portions of the aquifer at a rate of 5 to 25 feet per year, and horizontally at a rate of 130 feet per year. Tongues of nitrate-enriched ground water may be moving faster than the average estimated rate in local areas due to heavy pumping from wells.

Another investigation carried out in the same area of Nassau County during the period 1966 to 1970 by the U. S. Geological Survey involved a determination of the distribution of MBAS (methylene blue active substances - a detergent constituent) in ground water.[58] MBAS was found to be widely distributed in water from the shallow glacial aquifer, but relatively few analyses of well water showed concentrations greater than the U. S. Public Health recommended limit of 0.5 mg/l. Presence of MBAS in the deeper artesian aquifer is not a significant problem. Also, a slight downward trend in MBAS content during the five-year study period was indicated and may be due to natural dilution after a regional drought of the early 1960's and the introduction of a more biodegradable detergent in 1966. In the sewered area, the presence of residual MBAS in the glacial aquifer, after 10 to 20 years of public sewer operation, may be related to a combination of factors including continued infiltration of effluent from residual active or abandoned cesspools and septic tanks, leakage from sanitary sewers, and the slow rate of recovery in the quality of chemically deteriorated ground water after sewering.

State of Delaware -

In a 1972 report, John C. Miller of the Delaware Geological Survey states, "inspection of water analyses on file at the Delaware Geological Survey revealed that 25 percent of the shallow (less than 50 feet deep) wells in the state yield water with nitrate levels above 20 mg/l". [59] This indication of the potential for widespread ground-water contamination has led to an evaluation of some of the principal sources of nitrate enrichment of ground water in the state, including septic tank discharges.

Two suburbanized areas in the coastal plain were chosen for analysis of potential problems of ground-water quality degradation due to septic tanks. [60] The first area was selected on the basis that it is characterized by an extremely high water table and poorly-drained soils. In addition, there had been numerous reports of overflowing septic-tank systems during rainy periods. For comparison purposes, the second area selected is underlain by deep, well-drained soils on uplands. In both areas, homes are situated on one-quarter to one-half acre lots, each of which has its own septic tank and shallow well-water system.

The results of the study showed that in the first area of poorly drained soils, nitrate (as NO_3) levels averaged 6.9 to 11 mg/l during the period of sampling. A number of wells were contaminated by coliform bacteria. In the second area of well drained soils, nitrate content ranged from 22 to 136 mg/l, and concentrations in water from many wells was above the recommended U. S. Public Health limit of 45 mg/l. No wells were found to be contaminated with coliform bacteria.

The State investigators concluded that "the standard percolation test is not a suitable means for determination of the acceptability of a site for septic-tank effluent". Percolation tests in the first area were conducted during dry periods, and the favorable results led to installation of septic tanks. After installation, the systems overflowed during wet periods, and bacteriological contamination of domestic wells took place because of the introduction of sewage effluent from the land surface around well casings. On the other hand, the movement of the effluent through the fine soils has minimized the build-up of nitrate concentrations in the ground water. In the second area, the physical operation of the septic tanks has been successful because of the permeable soil sediments, which also apparently filtered out pathogenic organisms. However, nitrate contamination of ground water in the area is severe because of the favorable environment for oxidation of nitrogen compounds and rapid movement of septic tank and tile-field effluent to the water table.

Montgomery County, Maryland -

The Montgomery County Health Department has been issuing permits for septic tanks since 1945 and for wells since 1960. By 1968, this mostly suburban area had an estimated 15,000 to 16,000 wells and 16,500 to 17,500 septic systems. In order to determine the status of the safety of these systems, the Health Department conducted a number of housing surveys in selected portions of the county. Some of the results are of interest. [61)]

Based on these studies, it was estimated that more than 1,000 of the approximately 17,000 septic tanks were malfunctioning or had failed. About 800 wells, more than five percent of the total for the county, were rated as totally unfit for drinking water because they are yielding ground water contaminated from sewage effluent. In 1964, the county had passed an ordinance requiring grouting all new or reconstructed wells in order to seal the annular space between the outer well casing and soil. Basically, the code called for casing and grouting the wells to a depth of 40 feet or into solid rock. It was concluded that this measure had not been effective in protecting the safety of well supplies. Contamination of the aquifer from septic tank effluent eventually led to contamination of the water yielded from a well tapping the aquifer, whether or not the well was grouted. The study revealed that the most probable cause of contaminated well supplies was extensive use of underground disposal systems in areas underlain by fractured porous rocks that allowed free passage of sewage effluent to considerable depths in the aquifer. Also, the information obtained indicated that the average life of a septic system using current design standards may be as short as eight to ten years.

Northern New England Recreational Areas -

The development of recreational areas in the mountainous regions of the northern tier of New England States, namely Vermont, New Hampshire, and Maine, has been of concern to health authorities because of the unsuitability of some of these areas for installation of either high-capacity single septic tank systems serving central facilities such as motels, lodges, and condominiums or the proliferation of individual systems serving a growing number of vacation homes. Topography is rugged, soils are thin, and the bedrock aquifer is highly susceptible to the intrusion and transmission of pollutants.

These conditions are prevalent at one ski area, where studies were conducted on the effect of large quantities of sewage effluent being discharged to a septic tank and leaching field in shallow fill deposits overlying crystalline bedrock. 62) Laboratory tests were conducted on water samples taken from test pits and streams draining the area in which the leaching field was located. They indicated that certain constituents considered to have an adverse effect on public health were not being reduced to safe levels within distances up to 275 feet away. Phosphate and COD values up to 90 feet away were not appreciably different from those near the field. It appeared that the sewage effluent was moving laterally through the soil and was entering surface streams and perhaps fractures in the bedrock. In order to alleviate the problem, pretreatment was subsequently provided for the sewage effluent before discharge to the septic tank system.

Miscellaneous Effects of Septic Tank Discharges -

As mentioned previously, discharge into septic tanks of toxic chemicals or salts used for regenerating water softeners can lead to specialized problems of ground-water contamination other than those associated with typical household wastes. The use of water softeners in Connecticut, for example, and the discharge of salts used for regeneration of home units has been linked to high chloride concentrations in North Stamford, although it was concluded that the application of deicing salts on roadways was the most significant problem. 63) It was estimated that, based on regeneration practice in the area, as much as 2,000 pounds of salt are discharged to a septic tank each year from a home with a water softener.

Two noteworthy cases of ground-water contamination in Rhode Island may be indicative of specialized problems in the region related to septic tanks and cesspools. 64) The first involved contamination of domestic well water with metal plating wastes, which were being discharged to a septic system from a private residence. The owner had been running the plating operation in his home, and by the time the contamination problem was discovered, the concentration of nickel in the well water was 11.8 mg/l and copper 2.28 mg/l. In the second case, acid, commonly used by cesspool and septic tank owners to improve the operation of the system, migrated to the domestic well on the same property and noticeably affected the taste of the well water.

Future Trends

In spite of their potential for ground-water contamination, millions of septic tanks will continue to be used in the region, and their overall numbers may increase over at least the next decade. The reasons for this situation include:

1. The lack of other acceptable alternatives for domestic waste disposal in unsewered areas where septic tanks are correctly installed and adequately maintained and where geologic and hydrologic conditions are favorable.

2. Existing limitations on local, state, and federal budgets which prevent installation of public sewers to meet waste disposal needs of expanding suburban communities.

3. New environmental criteria calling for the upgrading of community sewage treatment plants. This slows down the expansion of these central systems into unsewered areas.

4. The continued resistence by residents in many parts of the study region to approve the large expenditures necessary for conversion from complete dependence upon on-site disposal systems to sewered communities.

5. The long time period required for a public system to become fully operational, even in areas where the density of housing and problems of ground-water contamination have justified to all concerned the need for conversion to collecting sewers and treatment plants.

Therefore, the need for improved methods of design and control of septic tank installations is obvious. A number of variations of traditional on-site disposal systems have been proposed or are being used in various parts of the United States. One example is the aerobic tank in which air is introduced and bubbled through the sewage to maintain aerobic rather than septic conditions for more efficient treatment of the waste. Some of these units also have mechanical filters. Another approach is the use of incinerator toilets or privies that have been proposed for areas particularly sensitive to contamination from septic tanks, such as lakefront lots. The principal drawback to these systems for single homes is the need for periodic mechanical maintenance and the comparatively high initial cost. Artificial mounds of soil or sand and gravel have been employed in areas where natural conditions are not suitable for an underground septic tank and tile field. However, the entire system, including the mound itself and leaching field, must be designed very carefully.

Probably the best approach to limiting future problems is better governmental control and planning. Zoning and land-use planning in areas where septic tanks will be required should be based on a thorough understanding of regional variations in topography, soils, aquifer characteristics, and recharge and discharge relationships involving ground water and surface water. An initial study in a particular region leading to recommendations on planning procedures and guidelines for on-site waste disposal facilities will be expensive and create political controversey but would be the most environmentally sound approach and could prevent errors that might be even more costly and controversial over the long term. Research is needed to develop the tools that can be used for decision making related to septic-tank feasibility and density. In this way, ground-water quality can be better protected.

Some methods have been developed and applied to septic-tank usage that illustrate the type of approach recommended above. The Water Resources Center of the University of Delaware, supported by funds from the U. S. Department of Interior, Office of Water Resources Research, has used a computerized technique to categorize land areas in the Christina River Basin into site classes on the basis of a common relationship to the water regimen. [65] A site's vulnerability to development is indicated by the cost of the measures necessary to protect water resources while still permitting development. One of the parameters used in the study was control of pollution from septic tanks. Sites were classified, for example, according to those areas where septic tanks should be banned on less than one acre, where septic tanks would be allowed only if public water supply was available, and where only single home aerobic sewage-treatment systems would be permitted.

Another approach employed in Connecticut by a Geology-Soil Task Force, consisting of representatives from state and federal agencies, involves a master-mapping technique in which as much natural resource information as possible is applied to a land-use problem, such as where to allow a particular density of septic tanks.[66] Soil characteristics, water-table elevations, rock types, slopes, etc., are mapped separately for the particular region in question. Guidelines, such as required depth to the water table, are formulated. These determine whether a particular piece of property or group of properties would be acceptable for the proposed density of septic tanks. The resource data for the region is collated on a single map, and those areas that meet all of the parameters set by the management guidelines can then be considered for additional on-site investigation.

Of course, codes, regulations and permit requirements are already in force in much of the region on a state and local basis. Strengthening the enforcement of proper sanitation practices undoubtedly would help to reduce the number of ground-water contamination problems. The need for this type of action plus educational programs for installers, developers, public officials, and planners was pointed out in a survey of septic-tank system installation practices in Connecticut.[67] This study by the Agricultural Engineering Department at the University of Connecticut showed that a wide variety of specifications were being followed by installers in the same general area including publications from the Federal Housing Administration, State Health Department, and U. S. Public Health Service; recommendations by local health officers; and instructions from consulting engineers.

The ban of certain types of pollutants that are discharged into septic tanks has also been tried in the region as a means for ground-water quality protection. The prime example is the Suffolk County, New York, ordinance passed in November of 1970 which prohibits the sale (but not the use) of laundry and manual dishwashing detergents containing alkyl benzine sulfonate (ABS), linear alkylate sulfonate (LAS), alcohol sulfate, and any other surface active agent which can be detected by the methylene blue (MBAS) test procedure. In effect, the ban removed virtually every brand-name detergent, all of them biodegradable, from stores in the County. Justification for the ban was linked directly to the need to protect the quality of ground water from further degradation by septic-tank effluent. This action came about only a few years after the detergent industry had spent in excess of $150 million to make its products biodegradable.[68]

Controversy over septic tanks, and their effects on ground-water quality will continue in the region for the foreseeable future. Hopefully, out of this controversy will come a more scientific and technical approach to the design and use of on-site waste disposal systems resulting in less of an impact of septic systems on ground-water quality.

BURIED PIPELINES AND STORAGE TANKS

Pollutants from leaky and ruptured buried pipes, sewer lines, and storage tanks can directly enter and contaminate aquifers. Within the study region, the principal pollutants from these sources are sewage, storm water, and petroleum products. Chemicals used in industrial processes have also been reported in a number of ground-water contamination cases.

Exfiltration and infiltration occurring in sanitary and storm sewers is a recognized engineering phenomenon. Where the system originally was poorly designed and improperly installed or where the pipelines are old and in disrepair, leakage of substantial quantities of poor-quality water into the soil system can take place, eventually leading to contamination of an aquifer. Storm sewers are especially subject to exfiltration because joints are normally not completely sealed against leakage. A comparison of the levels of selected constituents in street runoff and raw sanitary sewage is given in Table 28. As indicated by the table, the pollutional loads from both sources can be substantial. Thousands of miles of sanitary and storm sewers exist in the study region.

Petroleum and petroleum products are contained in hundreds of miles of transmission pipelines throughout the region and in thousands of home fuel and gasoline station tanks. Interstate and some intrastate transportation pipelines are regulated, but they are still subject to accidental rupture and external corrosion.

Details on the number of cases of ground-water contamination due to leakage from buried tanks and pipes that occur in the region each year are not available. However, Maryland alone had over 60 cases recorded by county health departments and the Maryland Department of Water Resources in 1969-1970. 70) The Pennsylvania Department of Environmental Resources estimates that 2,600 new or replacement subsurface storage tanks are buried in the ground in that state each year. 71) If those replaced have failed, then the product originally contained had been lost to the ground.

If a leak of gasoline, oil, or a chemical fluid occurs in the soil zone above the water table, the liquid pollutant will either remain in the vicinity of the leak, move within

Table 28. COMPARISON OF POLLUTIONAL LOADS FROM HYPOTHETICAL CITY-STREET RUNOFF VERSUS RAW SANITARY SEWAGE. [69]

	Contaminant loads in surface runoff from streets (lb/hr) [a]	Raw sanitary sewage	
		(mg/l)	(lb/hr) [c]
Settable + Suspended Solids [b]	560,000	300	1,300
BOD [b]	5,600	250	1,100
COD [b]	13,000	270	1,200
Total Coliform Bacteria	40×10^{12} Organisms/hour	250×10^{6} Organisms/liter	4.6×10^{14} Organisms/hour
Kjeldahl Nitrogen [b]	880	50	210
Phosphates	440	12	50
Zinc	260	0.20	0.84
Copper	80	0.04	0.17
Lead	230	0.03	0.13
Nickel	20	0.01	0.042
Mercury	29	0.07	0.27
Chromium	44	0.04	0.17

a) During first hour of a storm.

b) Weighted averages by land use, all others from numerical mean.

c) Loading discharged to receiving waters (average hourly rate).

the backfill in the trench or excavation, or migrate downward through the natural soil under the influence of gravity. The actual route and rate of travel taken by the pollutant depends on several factors including the volume of fluid released, the comparative permeabilities of the soil materials in the vicinity of the excavation, and the density, viscosity, and miscibility of the liquid. If enough of the fluid enters the soil system so that it is not completely exhausted by adsorption on soil particles, the pollutant eventually may reach the water table and if miscible with water, extend into the saturated zone. Subsequent rainfall can drive the pollutants that are coating the soil particles down to the saturated zone and add to the contamination of the water-table aquifer.

The above is a very simplified description of the mechanisms involved in contamination from buried tanks and pipelines. Considerable technical literature has been written on the most common type of pollutant, petroleum products. Especially valuable for general reference are those that describe research carried out in Europe. [10, 72 through 75]

Case Histories

So few case histories involving leakage of contaminants from buried tanks and pipelines have appeared in United States literature that it is worthwhile to describe in some detail selected occurrences that have been recorded in the northeast. These are outlined below.

Kings County, New York -

Leakage from sewers may be a principal source of the nitrate and total nitrogen in the ground water of Kings County, Long Island, New York, according to a recent study by the U. S. Geological Survey. [76] At the present time, the County is served by a dense network of sanitary and storm sewers; about 1,700 miles of common sewer lines as of 1962. The area is highly urbanized, and other potential sources of nitrate contamination such as agricultural activities and domestic water-disposal systems are lacking. Sewerage began in the northwestern part of the County in about 1850, and 1,300 miles of the sewer lines are more than 40 years old. Total leakage is estimated to be very high and actually may represent a significant source of artificial recharge to the ground-water system in the county. Total nitrogen content in water from key monitoring wells in the unconsolidated water-table aquifer ranges from about five mg/l to 30 mg/l.

Mechanicsburg, Pennsylvania -

The Ground-Water Section, Division of Water Quality, of the Pennsylvania Department of Environmental Resources has conducted two interesting investigations of pipeline leaks in the Mechanicsburg area of Hampden Township, Cumberland County. The first involves a sewage-line break and the second, leakage of gasoline from petroleum transmission pipelines. The area is located in a gently rolling limestone valley with approximately 10 feet of relief. The water table is very near the land surface and is extremely responsive to rainfall conditions. Ground water is contained in joints, fractures, and solution cavities of the limestone aquifer.

Sewer line break - 77)

In September 1968, the operator of a sewage treatment plant in the area noted a drop in the normal flow entering the facility. Investigation revealed that about 350,000 gallons of raw sewage had apparently been lost to the limestone aquifer through a rupture in a 15-inch diameter trunk line. The break in the sewer was attributed to an abnormally high rainfall, which had led to an increase in hydraulic pressure on the line.

Water samples were collected from private and commerical wells in the area and four pounds of Fluorescein dye was injected into the ground at the location of the break to serve as a tracer. Two days after the dye was injected, it was detected in a well three-quarters of a mile northwest of the break. Three to five days after the break had occurred, dye was detected in an additional 12 wells approximately one and one-half miles northwest. In many of the wells in which dye was detected, coliform bacteria counts were high on the first day of sampling but decreased with time, indicating that the main body of the raw sewage had passed through the area. In the portion of the aquifer affected by the pollutant, individual wells yielded water containing coliform organisms with a median value as high as 163 per 100 ml. Repairs to the sewer line were carried out and about 50 pounds of chlorine were flushed into the break site.

Gasoline pipeline break - 16,78)

In February 1969, a local businessman drilling an illegal drainage well for a parking lot discovered gasoline in the ground water underlying his property. The site is located near three petroleum product storage tank farms and two product transmission lines. After being informed of the condition, one of the pipeline companies pumped 55,000 gallons of gasoline out of the well in about one month.

In June 1969, the State Highway Department encountered gasoline in borings for bridge foundations. Further investigation, including the drilling of observation and gasoline removal wells and the use of a truck-mounted gas chromatograph which analyzed soil vapor samples taken from the upper two feet of the soil mantle, revealed that a layer of gasoline was floating on the water table in an area of about one-third square mile. The thickness of the gasoline layer was found to be as much as seven feet. Initial removal rate of gasoline was as high as 1,800 gallons per day from a single well. Between February 1969 and July 1971, 216,000 gallons of gasoline were pumped from about 40 wells in the area. In the two and one-half year period, the maximum measurable thickness of gasoline in wells shrank to less than one foot and the maximum rate of removal from any single well declined to 100 gallons per day.

One of the major problems encountered in the clean-up operation has been the fluctuation in the level of the water table. High water-table conditions caused by heavy rainfall periods have forced gasoline and gasoline vapors into basements of buildings. Also, abnormal rises in the water table can temporarily float the gasoline above the intakes of removal wells.

Montgomery County, Pennsylvania - 42)

In this case, a transmission pipeline leak caused an estimated 80,000 gallons of gasoline to enter the ground water and contaminate wells in the area. In July 1971, gasoline was observed in a 60-foot deep well and in August of the same year in a 247-foot well, both tapping a limestone aquifer. Pumping the affected wells to waste over a period of one year proved to be no longer useful in removing the gasoline after approximately 45,000 gallons had been recovered. The pipeline company then proposed use of natural biological agents to break down the remaining 35,000 gallons of gasoline, and this experiment has been approved by the regulatory agency involved.

The system consists of 24 wells into which 10 tons of nitrogen and 10 tons of phosphate will be injected as nutrients over a period of five months. Air will also be injected into the wells at a rate of 2.5 to 3.5 cubic feet per minute, in order to maintain aerobic conditions in the aquifer. The project will be carefully monitored to determine the success of this method for removing fractions of hydrocarbons that cannot be recovered through the use of wells, trenches, and other skimming procedures. The project is underway, but results are not yet available.

Tabulation of Case Histories -

Cases of ground-water contamination from leaky and ruptured buried pipelines and tanks were found in all of the 11 states included in this investigation. Unfortunately, very few have been studied in detail but a review of about 50 of the better documented cases reveals again that petroleum and petroleum products are the most common complaint. Sources of petroleum contamination from buried tanks included gasoline stations, commercial facilities and homes heated with fuel oil, fuel storage areas, and industrial plants. Most of the problems recorded were local in nature, for example, affecting five or six domestic wells in the vicinity of a gasoline station. However, others were more regional in nature, as in an area of Connecticut where the shallow aquifer along a five-mile stretch of a tributary to the Housatonic River reportedly is contaminated with hydrocarbons and chemicals, presumably from leaky gasoline station, home fuel oil, and industrial tanks. 79)

The effect on ground-water supplies caused by a leak from a home heating oil tank is illustrated by a case in New York State. The pollutant penetrated 20 feet of overburden and moved 700 feet through a dolomite aquifer, contaminating water from a 100-foot deep domestic well. A new well was drilled 150 feet away from the affected well, and within one month after start of pumping, the second well was abandoned because of oil in the water. It took three years for the body of oil to dissipate enough so that the second well could be used for domestic supply. 30)

A number of cases have been reported where wells have been affected by leaky sewers and industrial pipeline systems transporting chemical fluids. In Camden, New Jersey, at least one public-supply well, yielding a million gallons per day and tapping shallow coastal plain deposits, has been shut down because of high levels of chromium in the water. 80) The source of the problem is apparently due to leakage from municipal sewers in the general area that carry a heavy load of industrial wastes. In upstate New York, a pipeline carrying natural brine from the source to the location of the industrial plant where it is used for processing leaked periodically for many years. 81) The industry has had to replace many dug wells along the pipeline route with deeper wells.

Methods used for the control and solution of problems caused by leakage from tanks and pipelines have been only partially successful, especially with regard to hydrocarbons. Repairs to the source of contamination, of course, are immediately undertaken, but in a number of cases, it was not possible to detect the source. Flushing the area with water has been reported as a method for attempting to dilute the pollutant in the shallow aquifer zone; ruptured tanks have been dug out, and to prevent future problems, clay barriers have been installed in the excavation before a replacement tank was buried; and trenches and wells for skimming have been dug to remove hydrocarbons from the water table. Nevertheless, well owners in some areas of the region report that taste and odor problems from petroleum contamination of aquifers have existed for 20 to 25 years, in spite of all abatement efforts.

Future Trends

As in the case of spills, a certain proportion of ruptures, breaks, and leaks in buried tanks and pipelines is unavoidable, and contamination of ground waters near such facilities will be a continuing problem. Leakage from sanitary and storm sewers will continue because so many of these systems are old. It is doubtful that a major portion of the old leaky sewers will be replaced in the foreseeable future. Thus, even though the materials used and today's design and installation practices for new sewers have improved greatly, this source of ground-water contamination will remain an important factor to be considered in decisions regarding the siting and construction of water wells.

Much more promising from the standpoint of ground-water protection is the greater scrutiny by public agencies of major petroleum pipeline projects because of new environmental laws. Before the pipeline is constructed, codes and regulations call for consideration of factors involving design and management of the system related to possible effects of leaks on the underlying aquifers. For example, an oil pipeline recently authorized in Long Island, New York, that crosses important aquifers in the region, was equipped with special valving and all connections were carefully inspected when installed in order to minimize leakage from breaks or failures that might occur. Public-supply and domestic wells were mapped along the route to determine the sensitivity of water supplies to possible contamination. The flow of fuel oil through the line is carefully monitored so that losses in product can be quickly discovered, and an emergency program has been developed for containment and clean-up in the event of a leak.[82)]

Concern for the environment undoubtedly will lead to better protection of pipelines and tanks from corrosion, and the use of materials such as clay and tar to line excavations for tanks and even pipelines where leakage might affect nearby water wells. Most of these efforts are presently directed toward minimizing the possibility of fire or explosion or the escape of toxic substances. However, the need for protecting ground-water resources is becoming better recognized in the region because of the growing number of cases of contamination of water wells from hydrocarbons reported to state agencies each year.

Research is most needed in developing new methods for removing hydrocarbons from the ground-water reservoir. Abatement by pumping or ditching is widely used and only partially effective. However, other means for cleaning up petroleum contaminated soils and aquifers have been suggested that should be further investigated. They include water-flooding techniques to better control and collect the body of fluid for more efficient removal; biodegradation of hydrocarbons by aerobic and/or anaerobic bacteria; and the use of chemicals to precipitate or immobilize the pollutant.

APPLICATION AND STORAGE OF HIGHWAY DEICING SALTS

In those states that have colder climates and lie within the snow belt of the northeast region, road maintenance during the winter months is a major problem, especially in the densely populated, industrial-urban areas. The need for unimpeded vehicular travel on highways has led to increased use of sodium and calcium chloride by state and local agencies in coping with winter storms. Salt has become popular as a means of snow and ice removal because of its ease of handling as compared to such abrasives as sand and cinders, its efficiency in providing a "bare" pavement, and its relatively low cost. In fact, sodium chloride, or rock salt, is the least expensive of all deicing chemicals (costing about one-third as much as calcium chloride) and, therefore, is purchased in the greatest volume by state, county, and municipal agencies in the region.[83)]

Table 29 gives the estimated quantities of sodium chloride and calcium chloride used by state highway departments and the application rate for eight of the 11 states in region for the winter season of 1965-66. Total use of deicing salts in all eleven states for the winter period of 1966-67 is estimated at close to two million tons.[35)]

The large amount of salt used and the quantities of these soluble inorganic compounds applied per lane mile year after

Table 29. QUANTITIES OF SODIUM AND CALCIUM CHLORIDE USE AND THE APPLICATION RATE PER SINGLE-LANE MILE FOR THE WINTER SEASON OF 1965-66.[84)]

State	Calcium Chloride (tons)	Sodium Chloride (tons)	Quantity Applied (tons/single-lane mile)
Connecticut	8,000	74,600	8.98
Delaware	820	2,770	4.48
Maryland	465	44,893	6.82
Massachusetts	5,855	120,304	20.70
New Hampshire	540	82,737	11.95
New Jersey	3,195	17,495	3.33
New York	3,900	245,300	7.50
Vermont	500	83,122	18.22

Note: All figures represent use by State Highway Departments only.

year (more than 20 tons per lane mile per year for Massachusetts, for example, with an eight-fold increase in total salt applied between 1954 and 1971) should have an impact on both surface-water and ground-water quality. 85) Runoff from road surfaces eventually finds its way into streams and rivers within the drainage basin occupied by the highway or percolates into the soils adjacent to the highway. The sodium, calcium, and chloride ions in the soil can be carried down to the water table by the runoff water itself or during periods of recharge from rainfall. Contaminated water can then move through the saturated zone until it is discharged into a surface water body, has leaked into an adjacent aquifer, or is pumped from a well. Although sodium and chloride ions can both move through the unsaturated and saturated zones, the former is more attracted chemically to various types of soils. This characteristic accounts for the relatively higher ratio of chloride to sodium encountered in contaminated ground water than normally found in surface water receiving direct runoff of salt-laden waters.

Another source of ground-water contamination related to salts used for highway deicing is storage of this material in piles at central distribution points. There are well over a thousand such storage sites throughout the study region, based on conversations with highway officials, and in the fall, each holds from several hundred to several thousand tons of salt. The low solubility of rock salt permits outside storage over relatively long periods of time without hard caking or noticeable loss in volume. Thus, many such salt piles are left uncovered on open land. This condition is especially common where the salt has been mixed with sand, resulting in a large volume of stored material that would require an expensive structure if the pile were to be sheltered.

Rain falling on the stockpile dissolves a portion of the salts and can carry them into the ground-water system. Typically, salt-spreading trucks are washed at such storage areas, and infiltration into the ground of the resulting brine solution can aggravate the contamination problem. In some cases, drainage from salt piles and wash areas is collected and fed into dry wells. Thus, the pollutant is introduced directly into the geologic formation underlying the site.

The principal hazard of road salts contaminating water supplies is the potential for exceeding established public health standards for chloride concentrations. The U. S. Public Health Service Drinking Water Standards of 1962 sets a maximum limit of 250 mg/l for chloride, where more suitable supplies are or can be made available. [38] This standard also is adherred to by the various state health agencies in the region. If other water sources are not available, concentrations of up to 500 mg/l are generally tolerated.

In addition, medical authorities have recommended against the use of waters containing more than 20 mg/l of sodium for patients with heart disease, hypertension, renal disease, and cirrhosis, as well as for many pregnant women. [86] These potential health problems have led at least two states in the region, Connecticut and New Jersey, to adopt a limit for sodium of 20 and 50 mg/l respectively, as a standard not to be exceeded if better quality water is available. [87,88]

Other hazards include the possible corrosion of well casings, screens, and pumps. Also, substances have been added to deicing salts to prevent caking and to inhibit corrosion. For example, sodium ferrocyanide has been added to deicing salts to prevent caking. [84] Not enough is known about the solubility or toxicity of the additives nor their fate in the soil and ground-water system to comment further. Detailed chemical analyses to determine whether such additives are present in ground water contaminated by deicing salts should be incorporated into future research studies.

Some controversy has existed over the importance of highway deicing salts as a cause of increasing chlorides in ground waters of the northeast states. The controversy exists because there are many other sources that can contribute to rising levels of concentration of this ion in the subsurface environment. These other sources include septic tanks and cesspools, water softener regeneration, leaky sanitary sewers, landfills, air pollution, and ocean spray. Even drought conditions can lead to temporary increases in mineralization of ground water because of the reduced amount of fresh-water recharge during such periods. The pollutant can be concentrated in the soil zone during an extended dry period and then later carried to the water table in high concentrations during the initial periods of normal or above normal rainfall.

However, enough research has been conducted on this problem to at least establish a relationship between highway deicing salt and ground-water contamination. For example, F. E. Hutchinson of the University of Maine has studied environmental effects caused by an average annual application rate of 25 tons of sodium chloride to each mile of paved highway in Maine. [89] During the period 1967-69, water from approximately 100 wells was sampled at random locations along major highways. Although natural chloride concentrations from the various aquifers in Maine are normally less than 20 mg/l (see Table 14), the three-year average April chloride content of water from the sampled wells was 171 mg/l. About one-fifth of the wells yielded water exceeding the 250 mg/l chloride standard. Average distance from the roadway for all wells was 40 feet, with an average of 24 feet for those wells containing water with concentrations of chloride in excess of 250 mg/l average. The highest concentration of sodium encountered was 846 mg/l and for chloride was 3,150 mg/l. The level of contamination for almost all wells each year was less in August than in April, which is the month of greatest snow melt and runoff from the roadways.

Hutchinson also participated in research on sodium and chloride ion levels in the soils bordering major highways. 90) The findings of this investigation at 27 sites revealed that levels of these ions were greatest both nearest to the roadways and where salting had been practiced for the longest period of time. At one site, along the edge of a road embankment, sodium sampled before the highway was opened increased nearly five fold to 235 mg/l after only one season of salting.

Considerable research has been carried out and is still underway in Massachusetts regarding the environmental effects of road salt application and storage. In one recent study by Arthur D. Little, Inc., for that State's legislature, a correlation has been noted between the upward trend in use of road salts and the rising chloride levels in ground-water supplies during the same period. 86) Figure 31 shows this correlation.

Of course, increased activity involving other potential sources of contamination is probably contributing to rising levels of chloride concentrations, but the report concludes that deicing salts are the major cause. This theory is supported by a case of ground-water contamination in Burlington, Massachusetts, where the U. S. Geological Survey studied the potential causes of a problem of rising chloride levels in that Town's well supply. 91) In 1949, a suction-well system of 70 shallow wells tapping glacial sands and gravels was installed about 3,500 feet from a major highway, which was opened the same year. In 1961, when the Burlington Town Highway Department began storing salt, uncovered and approximately 400 feet from the well field, the chloride content of water from the wells averaged about 15 mg/l. As noted on Figure 32, the chloride concentration began to rise at a relatively rapid rate by 1963. In spite of such remedial measures as sheltering the salt pile from rain water in 1968 and banning the use of deicing chemicals on Town

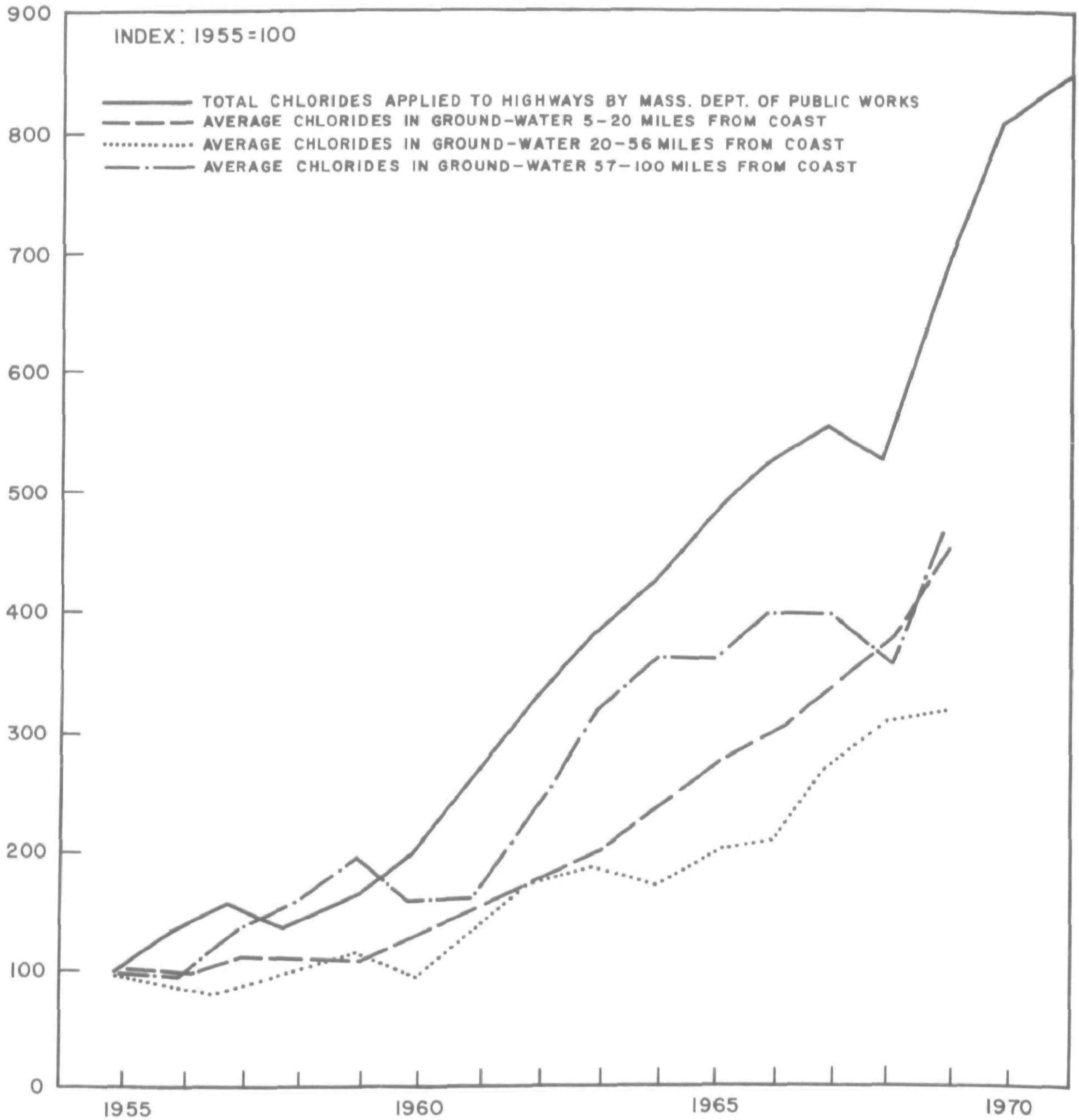

Figure 31. Index of increases in salt applied to Massachusetts state highways and chloride levels in ground-water sources, 1955-1971 86)

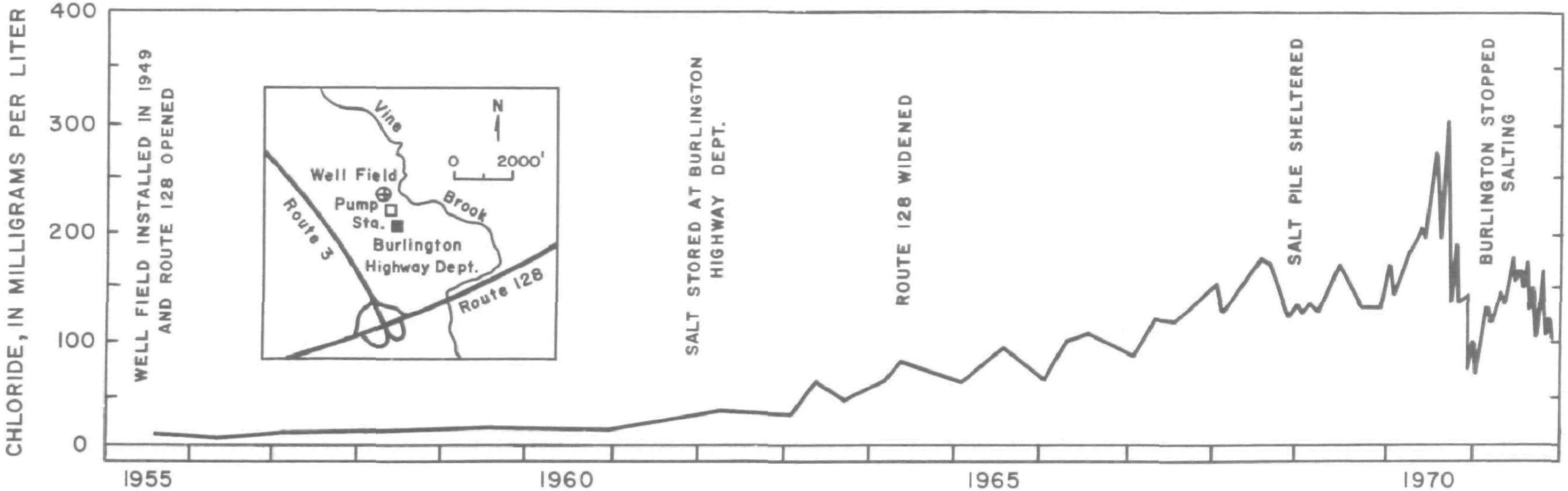

Figure 32. Chloride concentration in samples from main pumping station in Burlington, Massachusetts 86)

streets in 1970, the concentration of chloride reached a peak level of 283 mg/l in 1970 and was still at a level of over 100 mg/l in late 1971.

The U. S. Geological Survey developed a "salt-budget" for the Burlington well field area and, taking into account such factors as time of travel of contaminated ground water, rainfall effects, and the various activities in the river basin, tabulated the estimated importance of the various sources of contamination. Table 30 shows that, according to the estimate, 85 percent of the contamination, as of 1971, was related to highway salts and only 15 percent to other sources.

Case Histories

Additional supporting evidence of the relationship between highway deicing salts and ground-water contamination has been developed in this investigation based on data from the files of public health agencies and other environmental organizations working in the region. Information from selected case histories of those inventoried is given below.

As mentioned previously, a number of areas in the northeast have experienced a rise in chloride concentrations in water from municipal, industrial, and domestic wells. In some, as in Massachusetts discussed above, enough regional analysis has been made to indicate that the problem is related principally to highway deicing salts. In others, this source is suspected, but not enough data has been collected to pinpoint specific salt storage areas or road salting practices as the prime reason for ground-water contamination. For example, in many of the glacial sand and gravel aquifers of northern New Jersey, long-term records of the quality of water from a number of municipal wells have shown a gradual but significant trend of increasing chloride concentrations.[92,93] Some of these systems operated for decades with no indication of contamination but, starting in the early 1960's, chlorides began to rise in the well waters, and if the present rate of increase continues for another decade, many wells will be yielding water that exceeds 250 mg/l of chloride and that also contains high levels of sodium. Similar conditions were frequently cited within the course of this investigation by community sanitarians, county and state health authorities, and well drilling contractors, throughout the northern tier of states.

In addition, data on a number of specific and documented cases of ground-water contamination caused by storage or application of deicing salts were obtained and information on 34 of these is tabulated in Table 31. Those shown were

Table 30. SOURCES OF SALT CONTAMINATION OF THE BURLINGTON, MASSACHUSETTS WELL FIELD, 1971. [86]

1. Highway Salt:	
(a) Used by the Town of Burlington (including storage and application to roads)	40 percent
(b) Applied by Massachusetts Department of Public Works	30 percent
(c) Applied by Town of Lexington (42 percent of which lies in same drainage basin as the well field)	15 percent
Sub Total:	85 percent
2. Septic Tanks and Industrial Contamination:	15 percent
Total:	100 percent

Table 31. SUMMARY OF DATA ON 34 SELECTED CONTAMINATION CASES RELATED TO DEICING SALTS.

Type of problem	Road salting	Salt storage piles
Maximum observed chloride concentration		
100 to 250 mg/l	3	4
250 to 500 mg/l	5	7
More than 500 mg/l	3	12
Principal aquifer affected		
Unconsolidated deposits	6	11
Sedimentary rocks	0	4
Crystalline rock	5	8
Observed distance traveled by pollutant		
Less than 100 feet	4	3
100 to 1,000 feet	3	9
More than 1,000 feet	1	6
Unknown or not reported	3	5
Maximum observed depth penetrated by pollutant		
Less than 30 feet	3	2
30 to 100 feet	3	10
More than 100 feet	3	7
Unknown or not reported	2	4
Action taken regarding source of contamination		
Road salting banned or modified	2	-
Drainage modified	2	2
Salt storage pile removed	-	10
Salt storage pile enclosed	-	5
No known action	7	6
Action taken regarding ground-water resource		
Water supply well(s) abandoned	6	10
No known action	5	13

selected on the basis of the reliability and the amount of the data provided.

As indicated by the table, in a large percentage of the cases that actually came to the attention of regulatory agencies and, thus, are recorded, chloride concentrations are greater than 500 mg/l. For some of those cases listed, especially where salt storage piles were involved, chlorides exceeded 2,000 mg/l and sodium exceeded 100 mg/l.

Of interest is the fact that in most instances for which long-term records are available, chloride concentrations in the water from affected wells show seasonal fluctuations with the highest levels in early spring and the lowest levels in late fall. Bodies of contaminated water, which may have been introduced into the ground the same year or many years before, arrive at a pumping well as separate salt-water fronts. This condition temporarily raises the chloride concentration, which then declines somewhat until a new front arrives about a year later. This surging phenomenon in chloride content relates to the periods of maximum and minimum runoff and infiltration of salt-laden waters. Figure 32 illustrates the typical peak and trough character referred to and also the normal, overall rising trend in chloride concentration from year to year.

Studies by the U. S. Geological Survey at one Massachusetts site have indicated that salt water has moved through unconsolidated glacial deposits at a rate of about 200 feet per year from a salt storage pile to a municipal well 1,000 feet away.[91] Therefore, it takes more than five years for contaminated water infiltrated into the ground at the source to reach the well. At another site, it is estimated that the minimum period is six to twelve months, from the time of application of deicing chemicals to the highway to the appearance of contaminated water in the affected well. It should be noted that considerably more time is required than often appreciated for ground-water quality damaged by salt water to be restored to an acceptable condition after a remedial action, such as removal of a salt storage pile, has been taken. Pumping to waste, in order to reduce the volume of contaminated water in the aquifer, is a frequently used method for recovering use of a production well. However, the operator is rarely equipped with enough hydrologic information to be able to estimate how long and at what rate the well must be pumped before chloride concentrations will show a significant decline.

Another problem that becomes obvious in the review of case histories is the difficulty in replacing wells abandoned because of extreme contamination. After the pollutant has arrived at a domestic supply well or has moved into a municipal well field, an attempt generally is made to drill the existing wells deeper, especially when the aquifer consists of crystalline or sedimentary rocks. Another procedure is to move farther away from the suspected source of contamination and construct new wells on the same property. Because chlorides are not considered toxic, casing off the affected aquifer zone or moving away from the source but tapping the same formation are accepted as reasonable risks. However, even though initial chloride concentrations at greater depths or at new locations are low, the salty groundwater body is still present and may be within the influence of pumping of new wells. Ultimately, they too may have to be abandoned.

This situation is illustrated by a case in Freeport, Maine, where a 185-foot deep domestic well was contaminated by deicing salts from an uncovered storage pile and, to some degree, by salt applied to an interstate highway adjacent to the storage area. [94] When this well, which was 700 feet from the salt pile, was abandoned because chloride content reached 600 mg/l, a second well was drilled into the crystalline rock aquifer, 300 feet farther from both the salt pile and the highway. Initial chloride concentration of water from the new well was 50 mg/l, but within four months, it had risen to 2,000 mg/l. The limited size of the property available (which is a typical problem in finding new well locations in such situations) prevented moving the new well any more than the 300 feet.

In another situation in southeast Connecticut, a site was chosen, based on an extensive test-drilling program, for development of a future municipal well field. [31] During the initial testing in 1968, chlorides in water from test-production wells installed on the property ranged from 12 to 36 mg/l. Two years later, a gasoline leak from an underground storage tank in a nearby automobile service station was reported, and as a matter of routine, the city resampled the test-production wells, which were screened in glacial sand and gravel deposits. No hydrocarbons were found but chlorides had risen to almost 400 mg/l.

Investigation into the problem revealed that a salt storage area was located about 1,000 feet from the wells. All runoff from a salt pile and from truck washing operations had been drained into a series of dry wells over a 10-year period from 1955, when the facility was constructed, until 1965 when the salt pile was covered and the drainage system was converted to a concrete pipeline carrying the waste water away from the property. A water sample taken from a rock well used at the storage area also showed contamination, with a chloride content of 1,100 mg/l. Additional testing and pumping at the proposed well field indicated that almost the entire property was underlain by salty ground water. Not enough area was available to find new sites on the same piece of property or on adjacent properties to move far enough away from the existing problem. The proposed well field, capable of producing several million gallons of water per day, was abandoned.

In all of the cases used in the preparation of Table 31, water supply-wells had been affected. It should be noted that in many of these instances, the pollutant had traveled several thousand feet from the source to the affected well and had penetrated to depths of more than 100 feet, actually to almost 400 feet in a few wells. Most of the deeper wells tap crystalline rocks, which are particularly susceptible to relatively rapid movement of the pollutant through fracture zones and bedding planes with little chance for dispersion and dilution.

With regard to the action taken once the problem is discovered, little can be done if one or two domestic wells have been affected adjacent to a major highway because of the application of deicing salts to the roadway. However, if a problem of regional magnitude has come to the attention of authorities, a reduction in the amount of salt applied has been implemented and actual bans on deicing salts on a city-wide basis have been put into effect, at least temporarily, for a number of municipalities in the northeast.

Very often, if road salting or salt storage areas are pinpointed as a source of contamination, drainage in the area is modified as a partial solution to the problem. This procedure normally takes the form of collecting and piping the salty water away from the suspected ground-water intake area, often directly into a nearby surface-water body. In many cases, where contamination from a salt pile has affected a school well or municipal water supply, the stored salt is removed because it is much simpler and less costly than abandoning the well system. If this action occurs before gross contamination of a large portion of the aquifer has taken place, the wells may slowly recover. Salt storage piles also have been enclosed by a shed and the area paved to prevent infiltration of the salt-contaminated water. Although many of the states and municipalities in the region have begun a program to shelter salt storage piles, this process will take a long time to effectively accomplish because of the high cost and the large number of existing sites.

Treatment of the affected water is not practiced in the region because of the extreme expense in desalting water supplies. Some municipalities are mixing contaminated water with water from unaffected wells in order to dilute the salinity. Many domestic well owners report continuing the use of their affected supply. Because of the difficulty in drilling a replacement well on a relatively small piece of property, they "carry their drinking water."

Future Trends

A review of the literature reveals no adequate substitute for highway deicing salts. Therefore, it is reasonable to assume that their use will continue but probably not at the accelerated rate experienced in the past. In fact, some states, especially those in New England, have already begun programs for reducing the amount of salt applied each year to roadways. In Maine, equipment modification and driver education has reportedly reduced the amount of salt used by 20 percent without decreasing the effectiveness of deicing efforts. [95)] New Hampshire has embarked on a similar program and hopes to lower its current use of salt on state highways from an average of 150,000 tons per year to 100,000 tons. [50)] This action has been prompted, to a great degree, by the 250 complaints of road salt contamination of wells received each year. However, the few hundred thousand dollars that New Hampshire projects spending on the replacement of affected wells each year still does not make it economically feasible to consider changing over from salting to the very expensive alternative of increased snow-plowing.

The growing awareness that salt spreading could have an adverse effect on ground-water quality has led to efforts by agencies on various levels to modify drainage plans for proposed highways in an attempt to protect the resource. As previously mentioned, storage areas are also being cleaned up and more attention is being paid to covering exposed piles and keeping salty water out of the ground.

In early 1974, Massachusetts enacted a very strong law designed to curb oversalting of roads and resultant water pollution. [96)] It requires users of more than one ton per year of sodium chloride, calcium chloride or other road deicing chemicals to report how much they use and store. The state will compile data on amounts of salt used and, where surface waters or ground waters are threatened, can ban or restrict the use of salts. The passage of the law was prompted by information from the state's health authorities that the water supplies in 88 communities exceed 20 mg/l sodium.

Although other states will probably consider similar legislation, not enough is known regarding the overall trend in rising chloride and sodium being experienced in many parts of the region. Because road salting will continue, more research is needed regarding the role that deicing salts play in comparison with other potential forms of ground-water contamination. In addition, based on more knowledge of the environmental effects of highway salts, guidelines are needed for the siting, construction, and protection of wells on properties located near highways, the design of drainage systems where highways cross aquifer intake areas, and methods for studying, monitoring, and eliminating contamination problems when they occur. Finally, research is needed to determine the fate of deicing salt additives after they have entered the hydrologic cycle. For example, are these substances stable, do they react with soils, or do they remain permanently in solution in ground water and surface water?

LANDFILLS

The principal method currently used in the northeast for disposal of solid wastes generated by communities and industries is open dumping in landfills. Sites receiving refuse are operated by private profit-making organizations, which have contracted to communities and industries for the purpose of disposing of their solid wastes, or by public agencies such as municipal or county governments. In addition, numerous landfills serve one particular industrial site. Still others are used as uncontrolled community dumps by local residents.

No comprehensive inventory exists regarding the number and size of landfills in the states making up the study area, but an idea of the potential for ground-water contamination can be gained by a review of the data that are available. The information contained below was derived from a number of sources including published reports, files of public agencies, and interviews with personnel in private and governmental organizations. One regional analysis that should be noted and is most important with regard to municipal landfills is the 1968 national survey of community solid-waste practices.[32)]

Until recently, an evaluation of geologic and hydrologic conditions was rarely included among the various considerations that determined site selection for landfills in the northeast. Thus, one environmental hazard created by past refuse disposal practices is the possible effect on ground-water quality. Existing landfills or dumps invariably were placed on land that had little or no value for other uses. The site chosen was located, for example, in a marshland, an abandoned sand and gravel pit, an old strip mine, or a limestone sinkhole, each of which is a favorable environment for the development of ground-water contamination problems. The above statement holds true for the manufacturer who has a 20-acre plant site where refuse is being dumped in a low-lying wet area in a remote corner of the property, just as it does for the large regional municipal landfill that may be occupying a particular location only because it was the least objectionable site from a political and economic standpoint.

The situation in the City of New York is a prime example of the large amount of property required for refuse disposal and the type of land used for this purpose. At present, it has approximately 3,500 acres of landfills receiving refuse at a rate of 26,000 tons per day. [97] Almost all of these properties are filled marshlands, with the base of the refuse at or below the water table. In New Jersey, 331 landfills owned by municipalities, county agencies, or private contractors are consuming land at a rate of about 750 acres per year. [98] Some 10,600 acres not yet used for landfill operations are committed to such use in the future, but it is estimated that all of this land will be exhausted by early 1982. One hundred and eighteen New Jersey municipalities haul 36,000 tons of solid waste per week to landfills in the Hackensack Meadowlands, located within the northeastern metropolitan area of the state. Connecticut estimates that 200 acres per year are being consumed for landfills. [33] Of the 144 municipal sites surveyed recently in Connecticut, only 13 were satisfactorily meeting all requirements of the State's Department of Environmental Protection from the standpoint of ground-water protection. [99]

The State of Pennsylvania has developed some interesting statistics that bear on the number of sites that may be contributing to ground-water contamination. [100] It is estimated that within that state there are 2,617 "promiscuous" dumps existing along roadsides, and in open fields and lots. Of 648 major landfill sites investigated in a 1966-68 inventory, 258 were contributing to water pollution. The latter figure includes 30 located in strip mines. It should be noted that most of these sites were in existence long before Pennsylvania had a Solid Waste Management Act.

Landfills in the region are receiving a wide variety of materials including paper products, food wastes, septic-tank sludge, demolition debris, tires, automobiles, leaves, plastics, textiles, glass, aluminum cans, liquid chemicals, oils and hydrocarbons, street sweepings, dead animals, and water and waste-water treatment sludge. In municipal refuse, paper and paper products make up the major category by weight. Table 32 indicates the physical characteristics of typical municipal refuse.

An average of about 5.3 pounds of solid wastes per day per capita is collected in the United States. A more realistic figure on waste generation should be based on collected plus uncollected refuse. The total would then approach eight to ten pounds per day per capita, but still would not include some solid wastes from industry and agriculture that are disposed of on-site. [102)] If the eight pound-estimate is used, then at least 214,000 tons of solid waste is generated in the 11-state region each day.

The processes that can lead to contamination of ground water from the disposal of wastes in landfills are relatively simple. The various organic compounds in refuse (with the exception of most plastics) are decomposed or stabilized by aerobic and anaerobic organisms to simple substances that will decompose no further. These products of decomposition include gases and soluble organic and inorganic compounds. If sufficient water is available from precipitation, or from surface drainage in contact with the refuse, these compounds can be dissolved and carried with the water that infiltrates the landfill and ultimately recharges the ground-water reservoir or discharges into adjacent surface-water bodies.

Solid inorganic refuse, such as tin cans and metal pipes, can also be slowly dissolved by percolating waters, resulting in a solution with an increased concentration of metallic ions. Finally, disposal of liquid industrial wastes, septic-tank pumpings, and waste-water treatment sludges can contribute to an overall increase in dissolved solids concentration of water passing through the landfill. The term "leachate" has been applied to highly contaminated water contained in or directly associated with a refuse disposal site.

Not so simple is the composition of leachate and the changes in concentration that can occur as the various pollutants move through the subsurface environment. Significant indicators of pollution in leachate from landfills containing municipal refuse include BOD (Biological Oxygen Demand), COD (Chemical Oxygen Demand), iron, chloride, and nitrate. The interaction of CO_2 (Carbon Dioxide) with soil and rock materials as it travels through permeable soils may contribute to the hardness of ground water in the area and result in the release of iron and manganese held on soil particles.

Table 32. PHYSICAL CHARACTERISTICS OF MUNICIPAL REFUSE: TYPICAL 100-lb SAMPLE, MUNICIPAL REFUSE.[101)]

Item	Wet Weight (lb)	Dry Weight (lb)
Paper	48.0	35.0
Garbage	16.0	8.0
Leaves and grass	9.0	5.0
Wood	2.0	1.5
Synthetics	2.0	2.0
Cloth	1.0	0.5
Glass	6.0	6.0
Metals	8.0	8.0
Ashes, stone, dust, etc.	8.0	6.0

In addition, biological pollution can be associated with waters discharging from a municipal landfill. Heavy metals and other toxic compounds can be found in ground water containing leachates from municipal landfills where toxic wastes have been accepted, and from private landfills serving particular industries where special types of wastes are dumped.

The concentration of chemical and biological pollutants travelling through soil decreases with distance from the landfill. The effectiveness, however, of such processes as adsorption, ion exchange, dispersion, or dilution varies considerably with the type of pollutant involved, the characteristics of the soil underlying the landfill, and geologic and hydrologic conditions at the site. Thus, no broad generalizations can be made.

The volume of leachate developed by any particular landfill is a function of its absorptive capacity and areal extent, and the amount of recharge water available for infiltration. Most landfills assume a relatively flat surface with no vegetation, which is more conducive to infiltration than to runoff and evapotranspiration. They are normally covered with a relatively coarse-grained material, again increasing infiltration efficiency. Therefore, it is reasonable to assume that at least one-half of the annual precipitation can become recharge to the ground-water reservoir, after it has come in contact with the solid waste contained in the landfill. Average annual rainfall in the northeast region is 42 inches per year. Thus, a 100-acre site would be capable of producing 57 million gallons of leachate per year after field capacity of the refuse has been reached. The more than 10,000 acres set aside in New Jersey for landfilling, mentioned above, theoretically would be capable of producing 5.7 billion gallons of leachate in one year.

Research on the question of how long after abandonment a landfill can be expected to generate leachate has been minimal. However, one investigation under a grant from the U. S. Public Health Service to the Pennsylvania Department of Health sheds some light on this question. A study was made of a landfill in southeastern Pennsylvania, part of which had been closed in 1950 but was still producing leachate. This was sampled along with leachate from a new section of the same landfill site still in operation in 1970. The comparison of the chemical characteristics of the two leachate samples is shown in Table 33. It should be noted that there is a difference of a hundred-fold or more in BOD and COD between the leachate from the old abandoned section and the new section of the landfill. Differences in specific

Table 33. COMPARISON OF THE CHEMICAL CHARACTERISTICS OF LEACHATE FROM AN OPERATING SECTION AND A TWENTY-YEAR OLD ABANDONED SECTION OF A LANDFILL IN SOUTHEASTERN PENNSYLVANIA.[103] (All constituents in mg/l, where applicable.)

	Operating landfill	Abandoned landfill
Specific Conductance (μ mhos)	3,000	2,500
BOD	1,800	18
COD	3,850	246
Ammonia (NH_3 as N)	160	100
Hardness (as $CaCO_3$)	900	290
Iron (Total Fe)	40.4	2.2
Sulfate (SO_4)	225	100

Note: Samples collected in 1970

conductance, ammonia nitrogen, and sulfate are not as significant. Although concentrations of iron and hardness are considerably lower in the leachate from the older portion of the landfill, this site must still be considered a source of contamination, even 20 years after being abandoned.

Case Histories

The results of research on two landfills are described below in some detail. The first case is a continuing investigation of a regional municipal landfill at State College, Pennsylvania, by the Pennsylvania State University. It was chosen because it is a study of the character and movement of landfill leachate through unsaturated soil.[104,105] The second case history involves a municipal landfill in southern Connecticut. It is included because of its typical wetland location in an area where the water table is actually in contact with the refuse.[43,106] Finally, significant data from other selected case histories are tabulated, based on a survey of available information in the 11-state study area.

Case History Number One -

The State College, Pennsylvania, landfill occupies a gently sloping dolomite valley with the water table more than 200 feet below land surface. The approximately 100 tons of municipal refuse brought to the 108-acre site each day is placed, unprocessed, in trenches excavated into sandy clay to sandy-loam soils and then covered. In some portions of the landfill, the buried refuse lies directly on bedrock of Cambrian Age consisting of an interbedded series of dolomites, sandy dolomites, and quartzites. In other portions, the refuse is underlain by layers of residual soils which can be as much as 70 feet thick.

Suction lysimeters were placed beneath two cells (trenches containing refuse), one filled with waste material in 1962 and the other in 1967. During July, 1970 and at other periods, soil moisture and water samples were extracted at different depths from beneath the two refuse cells and analyzed for various physical and chemical characteristics.

The data collected indicate that the leachate front resulting from water percolating through the 1962 refuse cell, and to some degree through other cells nearby, had moved downward about 50 feet in eight years or at an average rate of six feet per year. Beneath the 1967 installation, the leachate front had moved at an average rate of 11 feet per year and had penetrated to a depth 30 feet below the bottom of the cell after only two years and nine months.

It has been concluded that leachate beneath the two cells has been reduced in mineral concentrations during its downward movement through the subsoil. The mechanisms observed, together with supporting evidence, include the following: 104)

1. Dilution and dispersion (decrease in chloride with depth)

2. Oxidation (Eh and pH measurements - decrease in BOD and iron with depth)

3. Chemical precipitation (decrease in soil extractable phosphate after leachate percolation)

4. Cation exchange (increase in percent base saturation of clays affected by leachate, and depletion of ammonia under reducing conditions - bacterial growth may also retard or remove ammonia)

5. Anion exchange (decrease in sulfate with depth)

However, even though renovation does occur, it is not sufficient to prevent highly contaminated water from moving to significant depths beneath the cells. For example, Table 34 shows the analysis of water collected in July 1970, from soil 36 feet below the 1962 cell.

In addition, water from a well drilled into the bedrock at the landfill site showed an indication of contamination from leachate entering fractures and sinkholes, or infiltrating through the soils along the valley bottom. Chloride concentration in water from this well, for example, was 50 mg/l during 1970-71 as compared to a normal for unaffected ground water in the area of about two mg/l. Alkalinity as HCO_3 was as much as 520 mg/l during the same period as compared to a normal of about 130 mg/l.

This research is especially significant when related to current regulations regarding design of new landfills in the study region. Many states call for a separation of three to five feet between the base of the refuse and the top of the water table as one of the protective measures against potential contamination of ground water. As indicated above, at least under some conditions, pollutants can move through unsaturated soils to depths greater than called for by existing and proposed codes. Consequently, Pennsylvania has been requiring the lining of new landfills with materials of low permeability in combination with leachate collection systems. Delaware has proposed the lining of new landfills constructed

Table 34. ANALYSIS OF LEACHATE FROM SOIL 36 FEET BELOW 1962 REFUSE CELL, STATE COLLEGE PENNSYLVANIA REGIONAL LANDFILL.[104)]
(All constituents in mg/l, where applicable.)

Specific Conductance (μmhos)	6,600
Chloride (Cl)	600
BOD	9,000
Ammonia (NH_3 as N)	40
Iron (Total Fe)	100

Note: Sample collected in July 1970.

in its Coastal Plain region. Also, instances exist in other states, such as New Jersey and New York, in which new municipal solid-waste sites are being lined with clay, bentonite, or plastic membranes in order to prevent the migration of leachate into the subsurface. Treatment of leachate collected from such sites is planned, but little experience exists with regard to the various methods that might be successful in the handling of this complex fluid.

Case History Number Two -

The results of the 1973 investigation described below were obtained from a detailed study of a 90-acre landfill site in southern Connecticut. The refuse, consisting of municipal solid wastes plus a small percentage of solid and liquid wastes from local industries, has been deposited in a wetland for more than 30 years. Portions of the refuse had reached a thickness of 30 feet above the original marsh level.

The purpose of the investigation was to determine whether the presence of the landfill had degraded natural conditions at the site to the point where it no longer was suitable for consideration as a future recreational area. To accomplish this task, a detailed program of test drilling, and chemical and physical sampling of surface water and ground water was carried out. Geophysical methods were employed along with other survey techniques to establish geologic and hydrologic conditions. Finally, multispectral imagery was used to help define areas where remaining vegetative communities had been affected by the presence of the landfill.

The site is adjacent to Long Island Sound, a salt-water body separating the Connecticut coast from Long Island, New York. The area occupied by the landfill is directly underlain by 40 to 60 feet of generally unsorted glacial sands and silts which, in turn, rest on crystalline bedrock. The landfill itself has a relatively flat surface and is covered with relatively coarse-grained fill or partially shredded garbage from a recently constructed volume-reduction plant. A separate portion of the site contains fly ash, landfilled by a nearby power plant.

The results of the investigation of conditions at the site revealed the following:

1. The water table has been raised more than eight feet into the refuse due to infiltration of precipitation falling on the landfill.

2. The abnormally high water table has adversely affected the remaining vegetation around the landfill and has created standing surface water bodies of leachate, where the water table intersects the land surface.

3. An average of approximately 80,000 gallons per day of new leachate is being formed and is moving through the unconsolidated sediments beneath the landfill at a rate of approximately 0.25-foot per day. This water is continuously discharging to Long Island Sound, standing surface water bodies, and streams draining the area.

4. The total volume, at any given moment, of ground water in storage that has been contaminated because of disposal of solid waste at the site is about several hundred million gallons. This body of contaminated ground water underlies an area approximately 3,500 feet long and 3,000 feet wide. It has been found in test holes to a depth of 60 feet below the base of the landfill.

5. High counts of coliform bacteria have been determined in the standing surface-water bodies affected by leachate and also in seeps and springs issuing from the landfill.

6. Very high concentrations of such constituents as alkalinity, total hardness, specific conductance, COD, ammonia, chloride, iron and manganese were found in water directly beneath the landfill itself. However, some renovation of contaminated ground water is taking place as it moves through the subsoils. Test wells drilled 200 feet or more from the landfill yield water significantly less contaminated than that found directly beneath the refuse.

Table 35 shows chemical analyses of selected constituents of water from wells drilled into the water-table aquifer underlying that portion of the landfill containing refuse and that portion containing fly ash. These analyses are compared with those of water from a well drilled 200 feet from the toe of the landfill and an off-site well, where the glacial aquifer is essentially unaffected by leachate from the landfill.

The table shows the typical contamination of ground water that has been affected by refuse, as indicated by the high concentrations of each of the constituents in water from the refuse-area well. In addition, the pH is on the acid side. When these concentrations are compared to those in water from the well 200 feet from the landfill, a marked difference is apparent, but ground water is still contaminated,

Table 35. PARTIAL CHEMICAL ANALYSES OF WATER FROM WELLS LOCATED IN AND NEARBY A LANDFILL SITE IN SOUTHEASTERN CONNECTICUT.[43] (All constituents in mg/l, where applicable.)

Well location	Off-site	200 feet from toe of landfill	Refuse area	Fly-ash area
Date sampled	5-10-73	7-12-73	7-6-73	5-10-73
pH	5.9	8.9	5.8	3.8
Alkalinity ($CaCO_3$)	8.0	540	1,700	3,885 [a)]
Total Hardness ($CaCO_3$)	64	300	2,240	540
Calcium Hardness ($CaCO_3$)	28	40	1,300	80
Specific Conductance (μ mhos/cm)	142	1,840	5,990	4,610
Chemical Oxygen Demand (COD)	34	NA	12,400	227
Ammonia (N)	0.018	NA	103	6.0
Chloride (Cl)	7.0	280	650	40
Iron (Fe)	0.25	2.4	63	252
Manganese (Mn)	0.08	0.14	12	6.25

NA - Not analyzed

a) Total acidity

with levels of such constituents as iron, manganese, and chloride above limits recommended for drinking waters. The quality of ground water beneath the fly ash is most interesting. The highly acid leachate created by infiltration of rain water through the fly ash apparently has dissolved precipitated iron, which occurs naturally in the underlying glacial sediments.

It has been recommended that the existing landfill be abandoned because of the inadequacy of the site for solid-waste disposal. An attempt will be made to contour the final shape of the landfill and cover it with a material of low permeability in order to increase runoff and decrease infiltration of precipitation into the refuse. If successful, this procedure would cause the abnormally high water table to decline, reducing the generation of additional leachate. The landfill also generates considerable gas, including methane and carbon dioxide, which will require venting as part of the final design.

The case history discussed above is typical of the situation at numerous landfills throughout the northeast. Large landfills placed in unsuitable sites can generate considerable quantities of leachate that enter the ground-water system. Also, if placed directly above the water table, a portion of the refuse can become permanently saturated and create problems of an esthetic nature in addition to those associated with contamination of ground-water resources. Finally, leachate flowing directly out of such landfills, and the discharge of contaminated ground water, can degrade the chemical and biological quality of nearby surface waters.

Although determination of whether toxic substances in ground waters associated with the sites discussed above was not a part of the studies, analyses of water from wells near some other landfills in the region have shown the presence of such pollutants. Information on this problem is included in the tabulated case histories given below.

Tabulation of Case Histories -

This inventory of ground-water contamination problems in the northeast uncovered about 100 cases in which landfills were pinpointed as the source. Table 36 summarizes the key data developed from 60 of these cases, selected on the basis of a high level of reliability of the information available. In addition to those obtained from interviews and public agency files, a number were taken from published sources and unpublished reports.[107,108,109)]

Table 36. SUMMARY OF DATA ON 42 MUNICIPAL AND 18 INDUSTRIAL LANDFILL CONTAMINATION CASES.

Findings	Type of Landfill: Municipal	Type of Landfill: Industrial
Assessment of principal damage		
Contamination of aquifer only	9	8
Water supply well(s) affected	16	9
Contamination of surface water	17	1
Principal aquifer affected		
Unconsolidated deposits	33	11
Sedimentary rocks	7	3
Crystalline rocks	2	4
Type of pollutant observed		
General contamination	37	4
Toxic substances	5	14
Observed distance traveled by pollutant		
Less than 100 feet	6	0
100 to 1,000 feet	8	4
More than 1,000 feet	11	2
Unknown or unreported	17	12
Maximum observed depth penetrated by pollutant		
Less than 30 feet	11	3
30 to 100 feet	11	3
More than 100 feet	5	2
Unknown or unreported	15	10
Action taken regarding source of contamination		
Landfill abandoned	5	6
Landfill removed	1	2
Containment or treatment of leachate	10	2
No known action	26	8
Action taken regarding ground-water resource		
Water supply well(s) abandoned	4	5
Ground-water monitoring program established	12	2
No known action	26	11
Litigation		
Litigation involved	8	5
No known action taken	34	13

The landfills have been separated according to type. The 42 municipal landfills are operated primarily as sites to receive domestic garbage and other wastes generated in a community, such as leaves, road sweepings, construction debris, and commercial rubbish. Many of these also accept septic-tank pumpings, sewage-plant sludges, and some industrial sludges and liquids. The 18 industrial landfills listed are privately owned and accept primarily industrial solid wastes from manufacturing processes and some sludges and liquids from water and waste-water treatment systems. The vast majority of these serve one industrial site and are located on the plant property. A few are operated by contractors who accept waste from several industries in a particular area.

Although more municipal than industrial landfills are represented in the table, the latter are much more abundant in the northeast. However, the location and even the existence of industrial landfills rarely are recorded with any public agency. Thus, they are not inspected on a routine basis, and problems do not become evident unless ground-water contamination is obviously taking place. In the case of the municipal landfills, although their locations are generally known to regulatory agencies, few are monitored and, again, contamination of ground water normally takes place unobserved.

The most important aspect of Table 36 is that there are thousands of other landfills in the northeast located in the same types of geologic environments and designed in the same manner as those appearing on the table. There is no technical or scientific reason why the vast majority of these are not additional sources of ground-water contamination.

The lack of ground-water monitoring is indicated by the high number of cases in Table 36 where contamination of surface water is reported as the principal damage. Many problems are first observed when the discharge of contaminated ground water affects nearby surface waters, which are more often subjected to periodic measurement of water quality than are ground waters. The cause of pollution in a stream or lake near a landfill can be traced with little difficulty. In addition, it is considerably less costly, if contamination is suspected, to sample ground-water discharge from the landfill in the form of seeps and springs than it is to drill and test water from observation wells. Thus, because the damage done to the aquifer is not known, the problem is reported initially as one of surface-water pollution.

As indicated, there are a number of instances in which water-supply wells have been affected by municipal and industrial landfills. In some cases, the wells must be abandoned, especially where public supplies are involved and chemical concentrations exceed recommended health limits, or a toxic substance is present in the water. An example of this is the loss of 10 percent of the well-supply capacity of the City of Newark, Delaware, because of contamination from a community landfill. [110)]

A number of examples exists where only the aquifer has been affected so far, but the plume of contaminated ground water is moving toward and threatening a well supply. Such a case was recently discovered in southern New Jersey where leachate, containing up to 18 mg/l of lead, has traveled at least 500 feet through coastal plain deposits toward city supply wells located 4,000 to 6,000 feet away from an industrial landfill. A ground-water monitoring program has been established and the landfill has been closed down.

In some cases, wells have been affected by a contaminant but their use is continued because either the various constituents have not reached critical levels or a treatment system has been installed. For example, several domestic wells in Ledyard, Connecticut, tapping a crystalline rock aquifer, were contaminated by styrene, an aromatic hydrocarbon. The maximum lateral observed distance of travel through joints and fractures was 110 feet, to a well 180 feet deep. Activated-charcoal filters were installed for treatment on some of the affected wells. The source of the contaminant, partially-filled drums of styrene that had been buried at various locations in the area, was removed by excavation of both the drums and the affected soil. After removal of the source, it took about two years before styrene was no longer detected in the water from any of the wells. [111)]

Table 36 also shows that in most of the cases recorded, the principal aquifer affected consists of unconsolidated eposits. Because the wastes are disposed of at land surface, it is these shallow deposits, which mantle the bedrock throughout the region, that are affected first. Furthermore, many landfill sites are chosen where there are relatively thick beds of sand available, which can be used on-site for cover material or can be trenched easily for burial of the refuse.

In a few instances, such as that described above in Connecticut, the contaminant infiltrates through the overburden into the bedrock before discharge to a surface-water body. In others, the solid waste is deposited in direct contact with a bedrock aquifer, for example, at such sites as strip mines, sinkholes, and abandoned deep mines. Garbage dumped over a period of many years into a deep abandoned and flooded mine in northern New Jersey has contaminated at least two wells in the area.[112] The methane content in water from both wells, one of which is 250 feet away from the mine shaft, has been rising over the years, as have chloride and iron concentrations, which have reached levels of 160 mg/l and 16 mg/l, respectively.

Toxic substances were reported associated with contamination from industrial landfills in almost all cases, because materials containing heavy metals and synthetic organics, for example, are a part of so many manufacturing processes. Also, hazardous industrial wastes are kept on-site at many plants because they are unacceptable at municipal landfills. Toxic substances would probably be observed at more municipal landfills if more detailed analyses were made of the leachate. Typically, the lack of staff and budget prevents a public agency from conducting complete analyses on enough samples to definitely establish toxicity. In contrast, the type of product disposed of in the industrial landfill is an excellent indication of the nature of the pollutant, and an analysis of selected constituents can be run initially if contamination is suspected.

Determination of distance and depth penetrated by a pollutant requires a rather elaborate test-drilling program, and therefore this information is not available for many of the landfills included in the table. The data shown were based on those cases where water-supply wells had been affected, and distances and construction details for the affected wells had been reported by the investigating agency or organization. In a few instances, monitoring wells had been installed or a detailed investigation, including test drilling, had been carried out. One such case involves a large regional landfill in southeastern New York State.[113] Here, test wells drilled into a 60-foot thick municipal landfill situated in a wetland have shown contaminated ground water to a depth of 70 feet below the base of the landfill. The aquifer underlying the site consists of lacustrine and coarse-grained glacial sediments. The leachate bailed from wells located in the landfill itself and drilled into the water table, which had risen a maximum of 14 feet above the old marsh level, contained high concentrations of such constituents as chlorides, total dissolved solids, total hardness (as $CaCO_3$), and iron (2,900 mg/l; 9,416 mg/l; 480 mg/l; and 48 mg/l, respectively). Natural ground water from the same aquifer in this area is of high quality.

One interesting aspect of that investigation is the fact that anomalous temperatures could be used to trace the plume of contaminated ground water as much as 700 feet from the toe of the landfill. For example, the termperature of ground water at the top of the water table within the landfill itself was 120°F. Seven hundred feet away and 70 feet below the landfill ground-water temperatures were still three degrees above the normal 51°F for ground water in the region.

The lack of any cases of industrial landfills where the maximum distance traveled by the pollutant is less than 100 feet may be related to the fact that most of the industrial sites are located on private lands, and the contamination does not become a matter of public concern until the pollutant has moved beyond property limits. Also, only a small percentage of industrial wells are sampled by regulatory agencies, and if contamination is dicovered by the industry in its own wells, there is an obvious reluctance in reporting the problem to local and state health authorities. To date, little regulatory action has been concentrated in this area.

Because of the large volumes of waste material involved, removing the source of contamination when dealing with landfills is obviously almost impossible. Thus, most of the cases included in Table 36 are listed under the category "no action taken". In a few, involving small quantities of toxic wastes, the material causing the problem was excavated. In others, the landfill has been closed, but this alternative also is difficult to accomplish because a new landfill site must be found and approved, or new facilities must be designed and constructed for handling the waste in a manner different from landfilling, such as recovery, treatment, or incineration. Even in cases where well supplies have been affected, abandonment of the wells is a last resort because of the high costs involved in developing and piping a new source of water supply.

Finally, a few landfill contamination cases are known to have resulted in litigation. This procedure normally takes the form of a local or regional regulatory agency using existing laws in order to force the polluter to take action in cleaning up the problem. In one instance, the Federal government has brought action against a county landfill and based the suit on the 1899 Refuse Act.

Future Trends

Because water pollution associated with landfills is becoming such an obvious problem, state and other regulatory agencies in the region are in the process of preparing new regulations or modifying old ones to better control this activity. To a large degree, these are directed toward the design and siting of new municipal landfills. Industrial landfills will continue to be difficult to control, if located on a particular plant property, unless more successful methods for inventorying solid-waste sites are developed, perhaps using advanced aerial photographic techniques.

New regulations normally call for geologic and hydrologic investigations of proposed sites and require such information as water-table elevation; direction of ground-water flow; distances to existing well supplies in the area; depth, thickness, and character of the overburden; and details of the bedrock aquifer. Although there is much variation in the details included in regulations and guidelines, a 60-inch separation between the highest anticipated level of the water table and the base of the landfill is a typical requirement. A buffer zone of 50 to 100 feet between the refuse area and the property boundary is called for by most agencies. Distances to the nearest operating wells normally are not specified but are to be determined on a case by case basis. Finally, the majority of new regulations call for 1) the sloping of the surface of the landfill to maximize runoff and minimize infiltration, 2) prohibition or curtailment of the dumping of hazardous or toxic solid and liquid materials, and 3) installation of monitoring wells.

Undoubtedly, these new regulations and the greater interest on the part of public agencies will help to reduce some serious ground-water contamination problems that otherwise would have occurred. However, the guidelines are based on insufficient research into such factors as the true character of leachate from various types of landfills, the ability of different soils to reduce the concentrations of different types of leachates, and the effects of landfill cover material, slopes, and thickness on infiltration of precipitation. Therefore, it is not known how effective the new codes will be in actually preventing ground-water contamination. In fact, some of the guidelines mentioned above may have little effect, based on known cases of ground-water contamination where pollutants have moved through unsaturated materials and have traveled horizontally for thousands of feet.

Some new landfills in the region are being constructed with clay or synthetic liners. These are used in combination with a system of drains to collect leachate before it can seep into an underlying aquifer. One of the first of this type has been installed in Pennsylvania, in which an acid-resistant bituminous mat was placed on the base of a 160-foot deep, 10-acre limestone quarry.[114)] Others are being proposed or are under construction in sections of New York, New Jersey, Pennsylvania, and Delaware. The major problem involved with this approach is the lack of experience and difficulties involved in the collection and treatment of leachate. Undoubtedly, the use of liners will be required more and more in the study area, especially where critical aquifers would otherwise be threatened or where nearby existing landfills have already been proven as sources of ground-water contamination.

Another approach being considered toward diminishing the many types of problems involved in landfilling is to reduce the volume of solid waste to be handled. Alternatives already in practice or proposed include incineration, pyrolysis, composting, or recycling. All of these either create other environmental hazards, such as air pollution in the case of incineration, or are not economically attractive enough to have received the acceptance required to make a significant impact. Thus, solid-waste generation will probably continue to increase at its present accelerating rate, unless environmental restraints on siting, including requirements for artificial liners, make the various alternatives listed above economically more attractive. Finally, concern over air pollution and surface-water quality may actually lead to a greater use of the land for disposal of wastes that formally were discharged into these other two environments.

With the trend toward greater use of monitoring wells by public agencies as a means to regulate ground-water quality, it is reasonable to predict that there will be an acceleration of new problems discovered at existing landfills. Unfortunately, adequate alternatives for eliminating the landfill as a continuing source of contamination have not been developed, and, because of this, there do not appear to be any clear-cut guidelines or policies that can be followed. The same holds true for how to contain or remove the pollutant after it has entered the ground.

Contouring or grading and then covering the landfill with a relatively impermeable material on which soil can be placed and vegetation established is being attempted at a number of sites in the region as a means of limiting the formation of new leachate. However, not enough history on this method has been developed to comment on potential for success. Pumping from properly spaced and constructed wells is another alternative for containing or removing the pollutant, but this has been proposed only as a last resort. Pumping is a slow and costly process, which is not always successful and can create other serious environmental problems. Research on these vital aspects of ground-water quality protection is badly needed.

SURFACE IMPOUNDMENTS

Contamination of ground water caused by leakage of pollutants from any type of surface impoundment, either natural or man made, is dicussed in this section. Such an impoundment may be a rock quarry into which an industry is dumping untreated waste that is unacceptable for treatment by the local municipal sewage treatment plant. It can be a sinkhole in a limestone area where liquid and sludge from the cleaning of septic tanks are deposited by a local contractor, or it can be a kettle hole in the glaciated region used as a holding pond for metal plating wastes.

Some impoundments for wastes are constructed by diking off a wetland, for example, or by excavating a lagoon or basin in unconsolidated deposits. These sites are typically used for storing industrial and sewage sludges in order to settle out the solid material from the wastes or to allow evaporation or oxidation to take place. They may temporarily hold brines for later treatment and disposal or for concentration and recovery of heavy metals. Some lagoons and basins are lined with clay, concrete, asphalt, or plastic membranes.

Both lined and unlined pits are other widely used types of surface impoundments constructed to hold storm-water runoff from highways and from paved areas at industrial sites. They are normally designed to deliberately discharge liquids to the soil or to feed a buried sewer collection system. Some pits are used as sumps to house pumping installations for sewage, industrial wastes, or fluids from a particular manufacturing process. Concrete and metal sheeting are the most frequently used materials for lining.

The size of surface impoundments varies considerably. They can be a series of cooling ponds receiving thousands of gallons per minute of hot waste water and covering hundreds of acres. On the other hand, a small unlined pit can be only a few feet in diameter and used to dispose of highly toxic wash water from a photographic laboratory. Most lagoons, pits, and basins are relatively shallow, holding less than 10 feet in depth of material on the average at any given moment. Exceptions are deep quarries or mine shafts receiving liquid wastes and sludges.

Statistics on the number and location of surface impoundments that may be a potential threat to ground-water quality have never been compiled for the northeast. Pennsylvania has made the only known inventory on a regional basis. By means of low-level aerial survey flights conducted over selected portions of the state, it was estimated that more than 1,500 industrial waste impoundments exist in the Commonwealth of Pennsylvania. 36) Because lagoons, pits and basins are such a common means for treating, handling, and storing liquids and sludges, it is conceivable that seven to ten thousand of these impoundments are present in the study region. Their potential for leaking many millions of gallons per year of potentially hazardous materials into the ground-water system is significant enough to be of considerable concern to water regulatory agencies.

This concern is justified on the basis of a number of factors inherent to the design and operation of surface impoundments. First, few were designed with any consideration given to protecting ground-water quality, and many operate on the principle that at least some fluid will be lost to the ground. Typical is the so-called evaporation pond which contains industrial waste and only operates successfully in this humid region if enough leakage is taking place through the bottom and sides of the impoundment to create additional storage space for continued waste discharges. Many unlined surface impoundments are located in geologic settings that are highly susceptible for leakage to take place. Data on case histories collected in this investigation have shown that abandoned sand and gravel pits, sinkholes, swamps overlying permeable unconsolidated deposits, mine excavations in highly fractured rock, and other areas where pollutants have easy access to important aquifers are quite typical sites for surface impoundments. No general guidelines have been enforced until recently regarding siting or designing new surface impoundments from the standpoint of ground-water protection. Consequently, lagoons, pits, and basins are located and constructed to meet other criteria, such as convenience and lowest possible cost.

Even in the case of some lined impoundments, the potential for leakage can be significant. Various types of clay are probably the most universally employed lining materials. However, they are not impermeable, and enough volume of a highly concentrated pollutant can leak from a large lagoon to damage ground-water supplies under certain conditions. For example, a lagoon 20 acres in size and 10 feet deep, lined with a two-foot thick clay blanket with a typical permeability of 0.001 gallons per day per square foot can leak about 1.5 million gallons of fluid per year into the ground-water system. If the fluid is an industrial waste and little change in water quality from contact with the natural soil occurs before the pollutant arrives at the water table, then a potentially serious contamination problem can occur. If 1,000 feet is the distance from the lagoon to the nearest well tapping the water-table aquifer, and ground water is moving toward the well at a rate of 0.5 foot per day, it would take more than five years before the plume of contaminated water would be detected. Meanwhile, 7.5 million gallons of the waste water would have leaked into the aquifer.

It is quite probable that much leakage of fluids takes place through the sides of excavated lagoons and basins rather than the bottom which can become clogged with settled solids and sludges. In some well documented cases of ground-water contamination, it was the erosion of the natural soils or the rupture of artificial linings on the sides of the impoundment that allowed leakage to occur at a rate great enough to significantly degrade ground-water quality.

Another major concern is the general lack of metering of waste discharges into holding ponds, lagoons, and basins. If losses of fluids to the ground-water system are taking place, this condition generally continues unobserved for extended periods. In addition, the use of monitoring wells to determine whether leakage is occurring and is affecting ground-water quality in the vicinity of existing surface impoundments is rare.

Also, a large variety of wastes is treated in lagoons and oxidation and stabilization ponds. Most of the substances are complex, and many of the constituents that could find their way into ground waters are not normally included in routine analysis of water supplies. E. B. Besselievre in his book "The Treatment of Industrial Wastes" lists about 80 types of industrial, municipal, and agricultural activities in which lagoons and ponds are used as part of the waste-water treatment process.[115)] Where industrial and domestic sludges have been placed in surface impoundments, the solubility of heavy metals in rain water has not been researched in detail, nor has the fate of potentially toxic substances that might enter the soil system.

Case Histories

The results of the inventory of ground-water contamination problems involving surface impoundments, carried out as part of this 11-state investigation, emphasize the variety of the pollutants and the diversity of the origins of waste water that can be encountered. Table 37 is based on 57 cases of contamination taken from the files of public agencies and private organizations. Each involves a separate location

Table 37. ORIGINS AND POLLUTANTS IN 57 CASES OF GROUND-WATER CONTAMINATION IN THE NORTHEAST CAUSED BY LEAKAGE OF WASTE WATER FROM SURFACE IMPOUNDMENTS.

Type of industry or activity	Number of cases	Principal pollutant(s) reported
Chemical	13	Ammonia Barium Chloride Chromium Iron Manganese Mercury Organic chemicals Phenol Solvents Sulfate Zinc
Metal processing and plating	9	Cadmium Chromium Copper Fluoride Nitrate Phenol
Electronics	4	Aluminum Chloride Fluoride Iron Solvent
Laboratories (manufacturing and processing)	4	Arsenic Phenols Radioactive materials Sulfate
Paper	3	Sulfate
Plastics	3	Ammonia Detergent Fluoride

Table 37 (continued). ORIGINS AND POLLUTANTS IN 57 CASES OF GROUND-WATER CONTAMINATION IN THE NORTHEAST CAUSED BY LEAKAGE OF WASTE WATER FROM SURFACE IMPOUNDMENTS.

Type of industry or activity	Number of cases	Principal pollutant(s) reported
Sewage treatment	3	Detergents Nitrate
Aircraft manufacturing	2	Chromium Sulfate
Food processing	2	Chloride Nitrate
Mining sand and gravel	2	Chloride
Oil well drilling	2	Chloride Oil
Oil refining	2	Oil
Battery and cable	1	Acid Lead
Electrical utility	1	Iron Manganese
Highway construction	1	Turbidity
Mineral processing	1	Lithium
Paint	1	Chromium
Recycling	1	Copper
Steel	1	Acid Ammonia
Textiles	1	Chloride

where leakage of pollutants out of some form of surface impoundment has entered the ground-water reservoir. In most cases, water-supply wells have been affected, and this is the only reason that the specific incident has been reported or investigated. In a few, simply observing operation of the lagoon or basin has led officials of an environmental or health agency to investigate whether ground-water contamination has taken place. In others, the polluter has noted the loss of a highly toxic substance to the ground and has brought this to the attention of authorities. Wells emplaced before contamination was suspected and drilled specifically to monitor possible changes in ground-water quality were not listed as the reason for discovery of any of the cases.

The types of surface impoundments represented in the 57 cases vary considerably, but lagoons and basins are listed most frequently. An interesting example other than a lagoon or basin is a small limestone quarry located immediately behind a battery manufacturing plant in Pennsylvania. The impoundment was spotted during an aerial survey by a geologist of the State's Department of Environmental Resources. It was noted that the quarry contained water but should have been dry under natural conditions based on the geology and topography of the area. Further investigation revealed that the quarry had been used for about six years as a discharge area for plant effluent with a pH level of 2.9 and a lead content of 4.12 mg/l. The waste disposal practices were altered, but the extent of the damage of the aquifer remains unknown. [36)]

Other examples include a case in Maryland where a three-foot wide, 48-foot long, and 10-foot deep concrete canal, used for storage of radioactive material at a private laboratory, leaked an estimated 20,000 gallons of slightly radioactive water into a thin soil layer overlying Triassic shale and sandstone. The leak was reported to state authorities by the company, and to date, six monitoring wells have been installed in and around the facility to determine where the pollutant has traveled. A small amount of cobalt-60 activity has been picked up in some observation wells, and the investigation is continuing. Meanwhile, use of the canal has been curtailed. [116)]

An abandoned sand and gravel pit was used by a paint manufacturer in Maryland to place liquid and sludge wastes removed from a stream during a clean-up operation. Monitoring wells installed later on the edges of the pit and driven to a depth of 15 feet produced water with a chromium (hexavalent) content of as much as 7.2 mg/l. [117)]

Many of the pollutants reported in Table 37 are related to hazardous wastes, as indicated by the large number of heavy metals listed. The concentrations of these toxic substances can be very high at sites where the untreated industrial effluent is leaking from a surface impoundment and reaching the saturated zone almost unchanged in chemical composition. Concentrations of some of the heavy metals in water from a lagoon containing untreated industrial sludges and liquid wastes were: copper 5,250 mg/l; chromium (trivalent) 1,380 mg/l; and lithium 280 mg/l. The site was investigated by a public agency after a stream near an abandoned plant property showed indications of contamination. The source of pollution in the stream was traced to the lagoon which was leaking the waste effluent to the ground-water system. The contaminated ground water, in turn, was discharging into the stream. The problem is presently in litgiation. [118)]

The concentration of total chromium in water from a domestic well, 700 feet away from leaky lagoons containing metal plating waste, was measured at 150 mg/l in a recent incident discovered in New Jersey. [42)] The most grossly contaminated ground water encountered in this investigation is a case in which the pollutant was 10,000 mg/l arsenic. [14)] Liquids and sludges containing arsenate compounds had been deposited by a chemical company in unlined surface impoundments for many years, and the plume of contaminated ground water had reached a stream adjacent to the plant site where arsenic concentrations as high as 40 mg/l were observed. The lagoons were abandoned after the problem was recognized and the wastes stored in plastic-lined drums. Also, an attempt has been made to pump out the contaminated ground water. After 2-1/2 years of careful pumping and monitoring, concentrations of arsenic in both ground water and surface water have been greatly reduced, but the condition is still dangerous.

Few of the 57 cases in Table 37 have been investigated in great enough detail to develop statistics on size of area contaminated and the nature of the pollutant in the ground. There are reported instances of large plumes of contaminated ground water extending for several miles from waste lagoons, but the little information gathered has never been published nor verified by detailed subsurface exploration and testing. Even where some investigation has been carried out, a private company is normally involved as the polluter, and the information is not made readily available to the public, especially if litigation is involved.

However, to provide some insight into typical ground-water contamination cases, Table 38 has been prepared based on

Table 38. THREE CASE HISTORIES OF GROUND-WATER CONTAMINATION FROM LEAKAGE OUT OF SURFACE IMPOUNDMENTS.

Description of Surface Impoundment	Two disposal basins, 65x65x15 feet and one disposal basin, 130x54x15 feet	One storage lagoon approximately 50x50x10 feet	Series of lagoons and basins covering an area of about 15 acres and average about six feet in depth
Type of Waste	Aircraft manufacturing	Metal plating	Chemical
Principal Pollutant(s) Observed and Maximum Concentrations Reported in affected wells (mg/l)			
Chromium (Hexavalent)	40	2.3	-
Cadimum	10	-	-
Cyanide	-	0.4	-
Zinc	-	1.4	50
COD	-	-	5,000
Copper	-	-	135
Chromium (Total)	-	-	150
Nickel	-	-	10
Dimensions of Plume of Contaminated Ground Water			
Maximum Length (feet)	4,300	1,000	2,200
Maximum Width (feet)	1,000	200	1,200
Maximum Depth (feet below the water table)	70	60	30
Estimated Maximum Volume of Contaminated Ground Water in millions of gallons and year	200 (1962)	50 (1969)	20 (1972)
Year Reported	1949	1969	1971
Remedial Action(s) and Status of Problem	Periodic research and monitoring; affected wells abandoned; some treatment and reduction of waste effluent; concentrations of chromium and cadimum have declined but problem still present in 1974	Lagoon and affected wells abandoned; no further action; problem still present in 1974	Lagoons and basins sealed with cement and/or plastic liners; continuing program of monitoring; system of pumping wells installed to contain pollutants in area of plant site and in shallow aquifer zones; problem still present in 1974

three detailed studies in the region. The first is the well documented and frequently published case of the dispersal of plating wastes in ground water in southeastern Nassau County, Long Island, New York. The most complete discussion of this problem appears in U. S. Geological Survey Water Supply Paper 1879-G. [119] The other two investigations were carried out by Geraghty & Miller, Inc., one in southern New Jersey and the other in central Connecticut. [22,39]

All three situations are related to industrial waste water having leaked out of surface impoundments. This has resulted in a plume of contamined ground water migrating slowly toward an area of discharge. In two of the cases, major discharge is to streams draining the affected water-table aquifer. In the third, the pattern of ground-water movement was controlled by pumping from a series of water-supply wells, which were abandoned after contamination was discovered. What effect cessation of pumpage has had on the characteristics of the body of contaminated ground water is unknown.

In two of the three cases, the plume of contaminated ground water had moved beyond the property limits of the polluter before the problem became known and was defined. In only one of the cases is hydraulic control over the vertical and horizontal movement of the contaminated water being attempted by means of special pumping wells.

Future Trends

The severe cases of ground-water contamination related to surface impoundments, that have become known in the region, have led a number of states and at least one interstate agency to develop regulations and programs directed at controlling this problem. Some of these controls are broadly written to cover a wide variety of activities that might affect ground-water quality but are particularly effective in dealing with this source of contamination. For example, the Delaware River Basin Commission includes in their ground-water quality control resolution of December 12, 1972, all activities involving "the processing, handling, transportation, disposal, storage, excavation or removal of any solid, liquid, or gaseous material on or beneath the ground surface of the Basin." In addition, the resolution states "no substance or properties which are harmful or toxic concentrations or that produce color, taste, or odor of the water shall be permitted or induced by the activities of man to become ground water." [120]

Maryland has established its general control over leakage from surface impoundments on the basis of a discharge permit requirement. That state's regulation of May 1, 1973, states "Any discharge or disposal of waters or waste waters into the ground waters of the state will require the approval of the Water Resources Administration." 121)

Pennsylvania's regulations are more specific and refer directly to impoundments. 122) A 1971 Special Water Pollution Regulation includes the following: "no person or municipality shall operate, maintain or use or permit the operation, maintenance or use of an impoundment for the production, processing, storage, treatment or disposal of polluting substances unless such impoundment is structurally sound, impermeable, protected from unauthorized acts of third parties and is maintained so that a free board of at least two feet remains at all times." The regulation goes further to define an impoundment as "any depression, excavation, or facility situated in or upon the ground, whether natural or artificial and whether lined or unlined."

Of particular importance is the term "impermeable" in the Pennsylvania regulation which automatically calls for the use of artificial liners in any surface impoundment containing anything but natural waters. Artificial liners are also being required by the Delaware River Basin Commission, New Jersey, Maryland, Delaware and in a few counties in New York for new lagoons, pits or basins which will hold untreated industrial wastes. Also, lining old impoundments that have been found to have been leaking wastes to the underground is a common practice throughout the region.

Because of the awareness of this source of contamination, the rate of development of new problems should decline, especially in the southern tier of states (Pennsylvania, New Jersey, Delaware, and Maryland), where regulations are being enforced. However, what is needed is a broader understanding and acceptance by municipal and industrial waste treatment facility operators that surface impoundments must be sited, designed, and operated with greater attention paid to hydrologic and geologic conditions.

The development of guidelines, an approach being used by state agencies to protect ground water from contamination by landfills, might be considered for surface impoundments. However, before such guidelines could be established, additional research is required, as with landfills, on the characteristics and effectiveness of the different materials available for artificial lining. Acceptable methods for metering loss of liquids from lagoons, pits and basins must be developed and tested. More information must be made available on what happens to different types of soil beneath and around impoundments containing various wastes with respect to changes in permeability, adsorptive power, and potential for ion exchange. Finally, more must be learned about many of the wastes placed in surface impoundments, especially the municipal and industrial waste sludges, which if not already wet when impounded soon become wet from precipitation. What compounds can be leached from these sludges must be determined along with the ultimate fate of these compounds when they reach the saturated zone. In too many cases, not even the chemical make-up of the original material impounded is known in any detail.

What may be more important from an overall ground-water quality standpoint than the control of new surface impoundments are the thousands of existing and already leaking sites throughout the region. A major difficulty will be locating those that may be damaging ground-water quality. Many surface impoundments are on private lands and are therefore difficult to inventory, except by air. Industries and municipalities have not had to register the existence of surface impoundments with regulatory agencies in the past, and thus, no central statistical file exists in the various states on where they are and how they are used. Also, basins with a very small area of say only 2,500 square feet can be as potentially dangerous as extensive lagoon systems, depending on such factors as the type of pollutant being lost, the rate at which leakage is taking place, the susceptibility of the aquifer to extensive contamination, and the proximity of wells supplying drinking water. These small basins would be difficult to locate even from the air.

A second difficulty is how to contain the pollutant and clean up the aquifer that has been contaminated. Regulatory agencies hestiate to place heavy economic burdens on the owner of the leaky surface impoundment. Because of the problems inherent with attempting to remove a pollutant from an aquifer under the limitations of the present state of the art, clean-up operations when large volumes of contaminated ground water are involved are for the most part ineffective. In the long run, most of the pollutant is left in the ground. Cases of ground-water contamination first reported decades ago which still exist today are not uncommon. In some instances, ground-water contamination was dicovered after an industry had gone out of business or abandoned the site. Clean up in such cases can be difficult to enforce, and litigation over this and other conditions of ownership and responsibility can be time consuming.

Most efforts toward containment or clean up are hindered by what to do with the pollutant after it has been removed from the aquifer and brought to the surface. This is the situation in one of the cases shown in Table 38. The pollutant is too toxic to discharge into a nearby stream. The volume is too large to leave in the ground but too small to justify the construction of a special treatment plant on the site. If a nearby municipal or privately owned waste-treatment plant could be found to accept the effluent removed from the aquifer, then perhaps it could be taken away by tank truck at a reasonable cost. However, in this particular instance, the polluter no longer exists as a corporate entity, and it is questionable as to who would pay for any corrective measures. Except for abandonment of the waste lagoon and affected wells, the problem remains unsolved.

SPILLS AND SURFACE DISCHARGES

This section discusses ground-water contamination caused by hazardous and non-hazardous liquids that are discharged onto the land surface in an uncontrolled manner and then seep into the underlying soils. If the volume of the fluid is great enough, the pollutant can migrate down to the saturated sediments in the vicinity of the discharge, and ground-water quality will be degraded. Activities leading to spills and surface discharges can be separated into three main categories: poor housekeeping at large industrial complexes and airports; intermittent disposal of wastes at gasoline stations, in remote wooded areas, and at small commercial establishments; and failures of above-ground tanks and pipelines, or accidents involving railroad cars and tank trucks.

Spills and surface discharges at industrial sites are widely variable and differ in character from plant to plant. However, they are generally caused by boil-overs and blow-offs, by overpumping during transfer of liquids to or from storage and carriers, by leaks from faulty pipes and valves in product distribution systems, and by poor control over waste discharges and storm-water runoff. At airports, the washing down of planes with solvents and small spills of fuel can build up as an extensive body of hydrocarbons floating on the water table.

Examples of degradation of ground-water quality over broad areas due to poor housekeeping are well known in sections of the study region where there is a considerable density of industrial plants. Oil has saturated the soils beneath several refineries and petroleum storage areas in New Jersey.[112)] During periods of high water table, oil actually appears as pools on the land surface. Furthermore, storm sewers in these areas continuously discharge oil-laden ground water that has leaked into them. It is felt that even though there may be some leakage from underground pipes contributing to the problem, the principal cause has been a long-term build-up of ground-water contamination from periodic spills and from leakage of oil onto the ground from surface tanks and pipes. In south Philadelphia, Pennsylvania, gross contamination of the unconsolidated water-table aquifer has been attributed principally to intermittent and long-term accidental spillage of liquid chemicals and uncontrolled runoff from chemical stockpiles in this highly industrialized area.[123] The ground water contains some inorganic constituents in greater concentration than is characteristic of raw sewage.

Contamination of ground water has also occurred in the region from the intermittent dumping of pollutants on the land surface, especially at gasoline stations and other types of small commercial establishments. A recent study of the ultimate fate of automotive waste oil generated in Massachusetts revealed that 650 thousand gallons of the oil is dumped each year on the ground on or near service station premises.[124] Another two million gallons is disposed of in a similar manner by car dealers and garage owners, by operators of equipment at construction sites, by fleet operators on their premises, and by persons changing their own oil. Although industry disposes of most of its uncollected oil in town landfills, it is estimated that at least some lubricating, hydraulic, and straight cutting oils are dumped locally on the ground. Each year these hydrocarbons are added to the shallow aquifers of Massachusetts with little chance of biodegradation or any other process that would naturally remove them from the ground-water system.

In a recent study of the disposal and management of waste oil in 18 counties of the New York metropolitan region, it was determined that eight million gallons per year of auto lube and crankcase oil, which is apparently changed by individuals or others not working through filling stations, are either given to the neighborhood garbage collector or are simply dumped on the ground. Industry dumps another six to 21 million gallons per year in this same region.[125] Similar practices must be present throughout the region and contribute to ground-water contamination.

Dumping of small quantities of liquid wastes in and around other types of commercial facilities has been observed by regulatory agency personnel interviewed in this investigation. Open discharge pipes draining sinks in commercial laboratories are one example. Disposal on open or wooded lands of small quantities of liquids, when it is not economic to store them in drums or to haul to municipal waste treatment plants or landfills, is probably quite common at commercial establishments that are not served by community sewers. Although such facilities have cesspools or septic tanks, the liquids may be judged too potent to be allowed to enter and upset the septic system.

Accidents involving above-ground pipes and tanks, railroad cars, and trucks can lead to the release of large quantities of a pollutant at a particular site. For example, rupture of a surface pipe at an Air Force test facility in New Hampshire in 1957 spilled 30,000 gallons of jet fuel on the ground.[50] The crystalline rock aquifer underlying the site was contaminated so badly that in 1972, wells originally supplying the base with high quality water were still unusable, 15 years after the spill took place.

Case Histories

Table 39, based on data selected from case histories inventoried in this investigation, lists the type of pollutant documented as having affected ground-water quality. The table is divided into cases involving accidental spills where there was a one-time discharge of fluid onto the ground and those where long-term poor housekeeping has been traced as the source of contamination. In the former, the volume of the spill is given where the information is available. As can be seen, the majority of cases involve hydrocarbons of some form, and it is reasonable to believe that these are the most common pollutant in the region related to spills and surface discharges.

In every one of the 36 cases included in the table, operating wells or a surface-water body were noticeably affected. For this reason, the cases were recorded in the health department or other environmental agency files that were reviewed to develop the information for this study. Undoubtedly, hundreds and perhaps thousands of other instances of ground-water contamination of this type exist throughout the study region but have not come to the attention of those concerned with ground-water quality. It is important to note that, in about one-half of the 35 cases, either municipal public water-supply or high-capacity industrial wells were affected and had to be abandoned. In those where domestic wells were involved, usually more than one had to be abandoned in each instance.

Several case histories from New York and New Jersey are typical of the damage that can occur and illustrate the problem of contamination from spills and surface discharges. In the

Table 39. POLLUTANT REPORTED IN 36 CASES OF GROUND-WATER CONTAMINATION CAUSED BY SPILLS AND SURFACE DISCHARGES.

Spills	Number of cases	Volume of spill (gallons)
Gasoline	4	up to 2,500
Diesel fuel	2	up to 4,000
Fuel oil	2	up to 200
Caustic soda	1	Unknown
Fuel oil and gasoline	1	6,000
Formaldehyde	1	4,000
Jet fuel	1	30,000
Ketone and alcohol	1	300
Trichloroethylene	1	50,000
Chlorinated phenols	1	Unknown

Surface discharges	Number of cases
Nitrates	3
Phenols	3
Crank case oil	2
Fuel oil	2
Heavy metals	2
Ammonia and mercury	1
Chlorinated benzine	1
Chloroform tetrachloroethane	1
Diesel fuel	1
Gasoline	1
Manganese	1
Chromium	1
Sulfate	1
Water softener effluent	1

first New York instance, 50,000 gallons of trichloroethylene were spilled on the ground in a railroad accident.[126] At least seven private wells in the area were contaminated with up to 40 mg/l of the pollutant, which moved quite readily through fractures and solution cavities of a limestone underlying the site. Flushing the area with fresh water was undertaken in an effort to dilute the trichloroethylene, but this appears to have aggravated the problem by spreading the pollutant over a larger area.

In another case, several petroleum storage tanks were tilted during the flood conditions that struck portions of upstate New York in the spring of 1972.[127] The spillage resulted in an area of approximately one-half mile by one mile being contaminated by hydrocarbons. No action has been taken yet to remove the petroleum products from the ground, but some remedial methods may be attempted under the federal disaster relief program.

In a third case in New York, small quantities of liquid wastes from a fertilizer production operation were discharged onto the ground over a period of many years.[127] Nitrates as high as 100 mg/l have been found in water from nearby private wells, and methemoglobinemia cases have been reported. The manufacturer has begun to treat the wastes and as domestic wells become contaminated, to replace them with water from a central community system.

In New Jersey, well fields operated by a municipality in the east-central part of the state are yielding water containing high levels of iron, manganese, lead, zinc, and aluminum. The problem was investigated by the Bureau of Water Pollution Control, and it was concluded that spillage and generally poor housekeeping at industrial sites upstream of the well fields were two of the principal cause of the problem.[128] Pollutants seeped into the ground and were later discharged to or allowed to enter directly the streams that ultimately recharge the well fields. Other sources of contamination included discharges of wastes to an unlined pit, a ruptured or unconnected industrial sewer line, and accumulations of sludges from water treatment lagoons.

Abandonment of the affected water source is the most common means for coping with problems arising from this type of contamination. Successful means for removing hydrocarbons, the most common pollutants, once they have reached the water table and extended over a broad area have not been developed. Pumping from the affected wells or specially constructed wells and skimming from trenches or pits dug to the water table has had only limited success. In a number of cases, where a spill has been reported immediately, excavation of the soil before the hydrocarbon has had a chance to migrate to the water table has been successful in preventing a serious ground-water contamination problem.

Paving industrial sites and correcting poor-housekeeping practices have been undertaken in some instances where intermittent spills and surface discharges have been shown to have contaminated water from wells in and around such areas. Also, carbon filters have been used with some success to treat water from wells contaminated by hydrocarbons.

Future Trends

The accidental spill is an unavoidable hazard that is part of the risk inherent to the storing and transportation of fluids. Thus, the number of new occurrences of this potential source of ground-water contamination will continue at about the same or at an even greater rate in the future. It is in the handling of spills after they have taken place that better protection of ground-water resources can be achieved. In the past, for example, liquids spilled on highways have been removed at the expense of pollution to adjacent properties and aquifers in order to have a minimal effect on traffic flow.

Time appears to be the most important factor associated with minimizing the contamination of ground-water supplies from accidental spills. If clean-up operations are carried out quickly, especially when hydrocarbons are involved, then there is a chance to either remove much of the pollutant from the surface before it enters the ground or to excavate affected soil in the immediate area before the pollutant reaches the water table. On the other hand, if action is taken only after a broad area of an aquifer is affected, containment or removal of the contaminated ground-water body is almost impossible.

Recognizing the importance of quick action, Pennsylvania has adopted a regulation that requires individuals responsible for a spill to immediately notify the Department of Environmental Resources Regional Office when an incident occurs. If ground water is threatened, the Regional Geologist attached to the State's Ground Water Section attempts to respond within a maximum of two hours.[36] In this manner, a technical appraisal of the situation is available within a short period of time, and clean-up operations and assessment of damage can begin in a more orderly manner. Also in Pennsylvania, certain industries are required to develop a Pollution Incident Prevention Program, which establishes a specific procedure for informing the state of spills or other major pollution problems. New Jersey has a similar program including a "hot line" for reporting spills.

Certainly, the Pennsylvania and New Jersey approaches to this problem should be considered by other regulatory agencies throughout the region. Also, there should be more recognition and better understanding by the carrier and other industries of the need for reporting spills to the proper authorities. Finally, guidelines should be developed for state and local highway personnel, railroad operators, and industrial plant managers defining such procedures as who should be informed of accidental spills and how to handle the incident initially.

Industry has long appreciated the ills associated with poor housekeeping and a number of trade organizations such as the Manufacturing Chemists Association and the American Petroleum Institute have published manuals and educational booklets on the prevention and control of surface discharges.[73, 129,130] Nevertheless, more controls are needed on practices that can lead to contamination of ground-water resources beneath and in the vicinity of industrial, commercial, and construction sites. Elimination of open discharge of wastes to the ground surface, paving and control of runoff in areas susceptible to infiltration of pollutants, and maintenance of above-ground distribution systems are especially important and may require more attention from regulatory agencies. The long-term effects on ground-water quality of traditional practices of dumping waste petroleum products at the point of use should be evaluated and again controls established if the problem is of great enough magnitude to justify regulation.

The need for research into how to remove pollutants from an aquifer after it has been contaminated has been pointed out in other sections of this report. The specific problems involved with hydrocarbons are discussed in the section on "Buried Pipelines and Storage Tanks".

MINING ACTIVITY

A major activity in the 11-state study area that has resulted in a wide variety of ground-water contamination problems is mining. Coal, stone, sand, and gravel are the principal products, but iron, copper, zinc, and lead have been important minerals to the region in the past. Extraction of salt by solution and underground excavation, carried out principally in western New York State, is not included in this section. The mining activity itself does not normally lead to ground-water contamination. Problems that have occurred have been mostly related to the handling and transportation of brine solutions, and they are characteristic of ground-water contamination occurrences from leaky pipelines, spills, and surface impoundments.

Mines in the northeast are of two basic types, surface mines and underground mines. Economics dictate the nature and extent of the mining. Where the ore deposit is close to the land surface or where rock is incompetent, surface mining is the most economical means of extraction. Where the mineral is deep or is unworkable from the surface because of local geologic conditions, shafts and drifts follow the trend of the deposit underground. Many mines in the area have been opened and closed periodically over the years depending on market conditions for the particular product.

The number and size of mines in the northeast is not known in detail. Underground mines are hidden from view and many were never recorded or adequately mapped. Some idea of the amount of area involved in mining operations is indicated in Table 40, which lists the number of acres in each state disturbed by strip and surface mining as of January 1965. According to the table, Pennsylvania is by far the leading state because of extensive coal deposits. It also is the state with the most underground mines, again because of coal production. Table 41 lists the number of abandoned and inactive underground mines in the northeast. Figure 33 shows the principal coal mining areas of Pennsylvania and Maryland.

Because of the nature of mining, in which land as a resource must be consumed, the dollar value of production per amount of land used is high relative to that of all other industries except agriculture and silviculture. Last year in the United States, an average of 1,000 acres of land per week was consumed by active surface coal mine operations alone. 134) Reclamation may never fully restore this acreage. Even where mines are operated underground, there may be significant land consumption through the placement of waste piles and surface impoundments, and land subsidence and collapse.

Mining is one of the few activities causing ground-water contamination in the region for which the geologic and hydrologic setting has been extensively studied. Historically, the presence of ground water in mines has been a severe problem hindering operations, and a principal concern of the mining industry is keeping the work area free of water. For example, in the 1870's the Ueberroth zinc mine near Friedensville, Pennsylvania, was being pumped at a rate of 12,000

Table 40. LAND DISTURBED BY STRIP AND SURFACE MINING IN THE NORTHEAST AS OF JANUARY 1, 1965, BY COMMODITY AND STATE (acres).[131)]

State	Clay	Coal (Bituminous, Lignite and Anthracite)	Stone	Sand and Gravel	Iron Ore	All Other	Total
Connecticut	-	-	100	16,100	-	100	16,300
Delaware	200	-	200	5,200	100	10	5,710
Maine	400	-	4,400	28,200	100	1,712	34,812
Maryland	1,200	2,200	2,200	18,800	20	800	25,220
Massachusetts	700	-	1,200	36,400	1,100	900	40,300
New Hampshire	-	-	100	8,000	-	200	8,300
New Jersey	1,400	-	2,000	27,600	1,000	1,800	33,800
New York	1,700	-	12,500	42,200	700	605	57,705
Pennsylvania	10,400	302,400	24,400	23,800	8,800	402	370,202
Rhode Island	-	-	20	3,600	-	-	3,620
Vermont	-	-	2,300	4,000	-	400	6,700

Table 41. ABANDONED AND INACTIVE UNDERGROUND MINES IN THE NORTH-EAST AS OF 1966.[133)]

State	Coal	Metal	Nonmetal
Connecticut	-	6	3
Delaware	-	-	-
Maine	-	7	-
Maryland	564	7	-
Massachusetts	-	7	1
New Hampshire	-	24	3
New Jersey	-	26	-
New York	-	61	17
Pennsylvania	7,824	160	55
Rhode Island	-	2	4
Vermont	-	17	3

Figure 33. Principal coal areas of Pennsylvania and Maryland [134)]

gpm from a depth of 250 feet.[135] Underground mines are almost invariably below the water table, and surface mines are often excavated into the water table. Dewatering has led directly or indirectly to the two major ground-water problems resulting from mining activity -- a regional lowering of the water table, and excessive mineralization of water associated with mines. In an attempt to keep the working areas of the mine dry and to remove as much of the mineral deposits as possible, operators may lower the water table by allowing water to drain from the mine by gravity, by pumping water directly from the mine, or by the use of wells in the vicinity of the mine.

The effects of lowering the water table on the ground-water system may be threefold. In the first place, the volume of ground water in storage is reduced, thereby limiting ground-water availability. Second, the water level may fall below the intakes of productive wells in the area forcing their abandonment. Third, lowering the water table can expose minerals to the process of oxidation. Percolating waters can dissolve these minerals in significant concentrations.

It is the increased mineralization of ground water that is the problem of greatest concern with regard to contamination of both surface waters and ground waters. Many economic deposits in bedrock are associated with sulfide minerals, the most prominent in the northeast being that of coal with pyrite (FeS_2). Pyrite may be found in the adjacent sedimentary rocks such as shale, sandstone, and limestone, as well as within and between the coal seams. Other examples are the copper ores of New Jersey, which are sulfides.[136] Chalcopyrite is a principal copper mineral in Vermont, occurring in an iron sulfide ground mass.[137]

If there is no change in the hydrogeologic environment, pyrite and most other sulfides are stable under the conditions that exist below the water table. If the water table is lowered, oxidation of the sulfides takes place in the dewatered zone. Oxidation of sulfides by itself does not contribute to ground-water contamination because oxidation occurs above the water table. However, when water is brought into contact with the mineral system, for example, if a mine is abandoned and dewatering activities stop, the result is quite different. Oxidation of pyrite followed by contact with water produces ferrous sulfate ($FeSO_4$) and sulfuric acid (H_2SO_4) in solution. Downward percolating rainwater, or a rise in the water table will introduce this solution into the ground-water system, causing a drop in pH, and a rise in sulfate and iron content.

The highly mineralized water associated with mine workings is normally referred to as "acid mine drainage." Although there is no typical analysis for mine drainage and it can vary in quality from place to place, water discharging from coal mines has been divided into four general classes as shown in Table 42.

Other sources of ground-water contamination associated with mining activities include leachate from waste rock piles and leakage from tailing ponds. These processes of contamination are similar to those described in the sections of this report entitled "Landfills" and "Surface Impoundments".

Case Histories

The principal areas where ground-water contamination from mining activities is of importance are the regions of Pennsylvania and Maryland underlain by coal deposits. The major emphasis of regulatory agencies, to date, has been directed toward control and correction of the complex problems of acid mine drainage to surface waters. It is estimated that Pennsylvania alone has over 2,300 miles of streams that are adversely affected by coal mine drainage.[139)] Many of these streams contain water with a pH of less than 4.0, iron concentrations greater than several hundred mg/l, and sulfates greater than 1,000 mg/l. The problem of poor-quality water is of such long standing and is so areally extensive that contamination of both surface waters and ground waters is looked upon as an almost normal occurrence in the heavily mined regions. The widespread effects of mining have made it difficult to drill wells yielding a satisfactory quantity of water with acceptable quality. Dewatering and excavation of underground mines have created physical problems, in addition to water-quality problems, that make the construction of wells in some areas almost impossible. Thus, ground water as a source of supply has probably declined in importance.

Compilations of individual cases involving degradation of well-water quality are not available, but the problem has been investigated on a regional basis. The results of such a study in the Toms Run Basin located in Clarion County, northwest Pennsylvania, is probably typical of the effects that mining can have on ground-water quality.[140)] The area has been mined for coal, and drilled for oil and gas for nearly 100 years. Coal mining has occurred exclusively in the western half of the basin, in the extreme north and along the southwest edge. Oil and gas wells have been

Table 42. MINE DRAINAGE CLASSES.[139]

	Class I	Class II	Class III	Class IV
	Acid discharges	Partially oxidized and/or neutralized	Oxidized and neutralized and/or alkaline	Neutralized and not oxidized
pH	2.0 - 4.5	3.4 - 6.6	6.5 - 8.5	6.5 - 8.5
Acidity, mg/l, $CaCO_3$	1,000 - 15,000	0 - 100	0	0
Ferrous Iron, mg/l, Fe	500 - 10,000	0 - 500	0	50 - 1,000
Ferric Iron, mg/l, Fe	0	0 - 1,000	0	0
Aluminum, mg/l, Al	0 - 2,000	0 - 20	0	0
Sulfates, mg/l, SO_4	1,000 - 2,000	500 - 10,000	500 - 10,000	500 - 10,000

drilled throughout the entire basin into Devonian sandstones between 2,200 and 2,500 feet deep. The Mississippian and Pennsylvanian rocks of the area comprise a three-aquifer system separated by shale and siltstone confining beds. At the top of the geologic section lies the only mineable coals within a sequence of sandstone and shale.

The investigation showed that coal mine drainage has a deleterious effect on ground water. Highly fractured bedrock together with abandoned gas, oil, and water wells have allowed poor quality water to migrate from areas of mining into the principal fresh-water aquifers of the region. Because of deterioration of cement seals and casings, the abandoned wells act as conduits for interchange of water between the aquifers in the basin, thereby aggravating the problem. Small diameter, uncased holes drilled to define coal deposits also allow aquifer interchange. Detailed mapping of water-quality relationships in two of the principal fresh-water aquifers revealed a very low pH and abonormally high concentrations of iron and sulfate in the vicinity of the coal mines. Table 43 shows the effects of mining on ground-water quality for two of the major aquifers in the basin.

As mentioned above, slag piles and settling ponds are also sources of contamination from mining activities. In northeastern Pennsylvania, water with a zinc content of up to 200 mg/l has been leached from a slag pile at a smelter and has entered a shallow sandstone aquifer. The contaminated ground water is discharging into and severely affecting aquatic life in a nearby creek.[141] In Port Washington, New York, ponds used in a sand and gravel operation for settling silt and clay particles have contaminated several important coastal plain aquifers in the area.[142] The source of supply for the ponds is salt water from a harbor adjacent to the mining operation. Long-term use of the salt water in the sand and gravel pits, which cover an area of about two square miles, has raised the chloride content of some nearby shallow and deep wells from a normal level of less than 20 mg/l to over 1,000 mg/l.

Future Trends

As with so many other problems of ground-water contamination, mine drainage would essentially be ignored were it not for its surface manifestation. Active mines appear to be less significant as sources of contamination than are abandoned mines for a number of reasons. First, in an active mine, the water table is held at or just below the working floor of the mine in a parastable state, reducing drainage that has come in contact with oxidized minerals. Secondly, pol-

Table 43. SUMMARY OF WATER QUALITY IN THE TOMS RUN DRAINAGE BASIN.[141]

	pH	Total Iron (mg/l)	Sulfate (mg/l)
Lower Aquifer			
Non-mining areas	6.3 - 6.8	3 - 16	4 - 13
Areas near mining	2.9 - 5.4	25 - 160	30 - 620
Upper Aquifer			
Non-mining areas	6.5 - 6.7	10 - 15	10 - 15
Areas near mining	3.0 - 5.5	20 - 70	39 - 80

luted surface water discharges can be traced to the source mine, so operators are more careful about the water that they discharge. Finally, recently developed regulations in some states require engineering practices be applied to active mines that will reduce the volume of polluted water generated or discharged, both during operations and after abandonment. Unfortunately, the major volume of mine drainage comes from abandoned mines. Of the 1,500 significant mine discharges in the Susquehanna River Basin of New York, Pennsylvania, and Maryland producing acidity, 75 percent comes from abandoned mines. 143)

No single method to control acid mine drainage has been effective in all cases. Partially successful measures have been applied by mining companies and enforcement agencies, and they fall into the following categories:

1. Minimizing the water-mineral-oxygen content

2. Regulating flow of surface waste water

3. Protecting minerals from weathering and erosion following completion of mine operations

4. Neutralization of acid

One pollution abatement method for abandoned underground mines has been sealing with either air- or water-tight seals. In theory, the air seal prevents oxygen from entering the mine. In practice, the procedure has had minimal success. Such seals are created by constructing walls across mine openings or by collapsing portions of the mine.

Water-tight seals have become more popular for sealing abandoned mines. Theoretically, the water-tight seal should eliminate surface discharge, restore the pre-mining groundwater level, and exclude oxygen from the mine, provided that the bedrock has not been extensively fractured by the mining operations. Cost of water-tight sealing at Moraine State Park, Pennsylvania, was $1,266,213 for 65 mine seals, an average of $19,480 per seal. 144) Sealing boreholes or fracture zones can range from $100 to $1,200 per hole and sealing shafts from $7,000 to $25,000 per shaft. 145)

Neutralization of acid mine drainage and precipitation of iron has been an alternative proposal for controlling contamination. This method, however, carries a high cost of treatment. Capital cost of a mine drainage treatment plant in southwestern Pennsylvania was $200,000 a few years ago. Capital recovery costs run as high as $29,000 per year, and the annual outlay for lime can range from $12,000 to $64,000, depending on how much acid must be treated. To treat mildly acid water, one company incurred costs of $0.13/1,000 gallons; for highly acid water $0.72/1,000 gallons. [146)]

Preventing pollution from abandoned surface mines has been attempted by backfilling. However, this type of reclamation is also very costly. For example, backfilling recently cost $672,208 for 462 acres in the area of Moraine State Park, Pennsylvania. [144)]

Many of the northeast states have provisions in their water laws that can cover ground-water degradation due to mining activity. The difficulty of enforcement in the case of abandoned mines has been a major hindrance to alleviating the problem. Pennsylvania has water statutes specifically referring to operation of mines and disposal of mine wastes, including acid mine drainage. [34)] The Clean Streams Law (1965) requires that active mine discharge to surface water not exceed seven mg/l of iron, have a pH of six to nine, and have no acidity. [139)] Mining permits in Pennsylvania include a section on mine closing which must be approved by the Sanitary Water Board. [146)] These statutes have no effect upon pre-1965 abandoned mines.

The tremendous costs involved in correcting existing contamination of surface waters and ground waters from mining activities will prevent public agencies from making major headway toward solving this problem in the foreseeable future. Considerable research has already been carried out and is underway on the subject of mine drainage, which may lead to the development of more effective control over contamination from both abandoned and operating mines. However, at present, this source of contamination appears to be one that will continue as a significant problem in portions of the study region.

PETROLEUM EXPLORATION AND DEVELOPMENT

Exploration for and development of oil and gas resources is no longer a significant industry in the study region. Most of the petroleum exploration has occurred in New York and Pennsylvania; minor exploration has taken place in New Jersey and Maryland. Virtually no exploration has been carried out east of New York, where geologic conditions have been considered unfavorable for the formation of petroleum. Figure 34 shows the general area where oil and gas exploration and development has taken place.

Petroleum exploration and development may cause ground-water

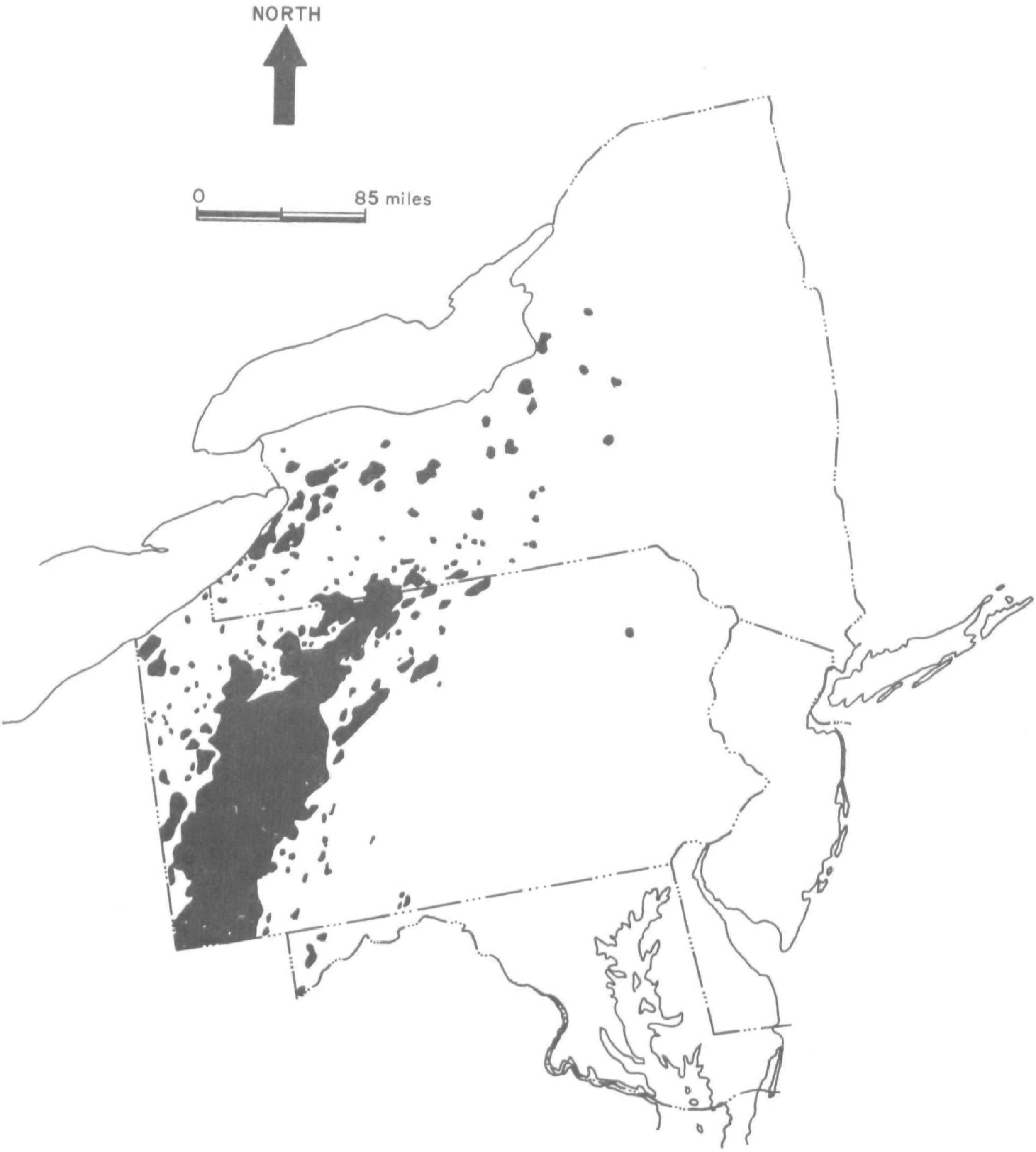

Figure 34. Principal oil and gas exploration and development areas 134)

contamination at sites of both active and abandoned wells. At many oil fields in New York and Pennsylvania, initial development took place around the turn of the century, at which time most of the production occurred, followed by a period of declining activity. Today, individual wells in the region produce a minimum of oil and gas, and large quantities of salt water must be separated from the fluid pumped from a well in order to obtain the petroleum product. Nevertheless, the number of active oil and gas wells in the region is still significant. In 1973, according to the Interstate Oil Compact Commission, there were 32,596 operating oil and gas wells in Pennsylvania, 5,400 in New York, and 15 in Maryland. During 1972, 1,632 wells were abandoned in Pennsylvania, 573 in New York, and one in Maryland. [147)]

The high yield of salt water from producing wells represents the principal threat to ground-water quality in fresh-water aquifers in the petroleum recovery region. Natural brines from deep strata tapped by the oil and gas wells is brought to the surface with the petroleum product. The oil and water mixture is then subjected to separation processes. The waste water produced from the separation process is a brine solution, which is usually disposed of in unlined settling pits or discharged to the ground. Pipelines and separation tanks may be in disrepair at these installations and can discharge to the surface. The saline waters from these various sources can infiltrate into shallow fresh-water aquifers and cause contamination.

Abandoned oil and gas wells also present problems to ground-water quality. For example, abandoned oil wells can discharge brine continuously, contaminating shallow fresh-water aquifers. Abandoned gas wells can discharge brine where the gas reserve has been depleted and salt water has migrated to the wells. Even where the exploration and production company has conscientiously capped and/or plugged the abandoned well, the casing may eventually leak or corrode, introducing brine or brine and waste oil and gas into near-surface aquifers.

Most of the oil and gas exploration in the study region has taken place on the Appalachian Plateau. This broad area of gently dipping rock strata has been dissected by major streams. The stream valleys have been partially filled with alluvium and are discharge areas for ground water circulating out of the uplands. Non-degradable pollutants such as brine introduced into leaky oil and gas wells in the uplands can eventually find their way to natural discharge areas in the valleys. As a result, regional problems can result from ground-water contamination due to petroleum exploration and development.

Case Histories

An estimation of the number of cases in which water wells in the northeast have been contaminated as a result of petroleum exploration and development is not possible. Individual cases and regional effects have been noted, but the overall problem has not been studied in detail.

One typical area where contamination from this source has been observed is Chemung County, in the western part of New York adjacent to the Pennsylvania border. Here concentrations of chloride and total dissolved solids in water from many domestic wells have shown a rising trend over many years. The upper bedrock of Chemung County is composed of a sequence of sandstone and shale, overlain by glacial drift. Within the major stream valleys, the sand and gravel deposits are productive aquifers. Elsewhere, the bedrock aquifer is utilized. Salt beds and zones of highly mineralized water are known to underlie the area at depth. Although never a highly productive petroleum area, a number of gas wells were drilled and later abandoned. It is believed that many of these old wells are conduits for the upward migration of the mineralized water. [148] Whereas natural chloride content of the shallow fresh-water aquifers in the County is less than 10 mg/l, concentrations of this constituent in water from domestic wells believed to be contaminated by brine from the deeper gas strata range from 100 to 500 mg/l. Analyses of water from many domestic, industrial and municipal wells in the Susquehanna River Basin in New York indicate similar conditions. [149]

In the Jamestown area of New York, salt beds are known to occur at depths of 1,500 to 2,000 feet below land surface. Oil and gas wells have been drilled through these beds, and it is suspected that many of those abandoned are now allowing mineralized water to migrate into the shallow freshwater aquifers. Water from some of the shallow wells is reported to also contain traces of oil and natural gas. [150]

In Venango County, Pennsylvania, discharge of oil field brines to unlined surface impoundments and directly onto the land surface has contaminated a number of privately-owned springs and wells used for water supply. The problem is under study by the state and some seepage basins have been moved. [141]

Future Trends

In a 1969 report on ground-water contamination from natural gas and oil production in New York, prepared by Leslie J. Crain of the U. S. Geological Survey, the author recommends that the first step toward attacking this problem should be "to delineate more exactly the area involved and to determine the magnitude of the pollution in these areas." 151) This statement clearly defines the present status of knowledge on contamination from petroleum exploration and development in the study region. For the most part, present contamination problems pass unnoticed because they generally occur in sparsely populated areas. However, as urban and suburban development proceeds, reports of contamination from petroleum exploration and development probably will increase. The continuing corrosion of casings and failure of seals in abandoned oil and gas wells also will aggravate the problem.

These factors, however, may be partially offset by a growing effort on the part of public agencies to have abandoned wells properly plugged. Pennsylvania has statutes that specifically refer to "the control and prevention of pollution of surface and underground waters resulting from drilling, operation, abandonment or plugging of oil or gas wells." 34) New York has had regulations on the drilling and plugging of wells since 1963. 152) However, little control can be exerted on operators who abandoned wells before such regulations were enacted.

SALT-WATER INTRUSION

Intrusion of salty water into fresh-water aquifers is one form of ground-water contamination that is widely recognized as a potential problem in the northeast. There are two principal regions in which salty water is found under natural conditions and, thus, fresh-water aquifers are prone to the intrusion of salt water caused by pumping from domestic, municipal, and industrial wells. The two regions are shown on Figure 35 and are referred to in this discussion as the Coastal Region and the Inland Region. The former borders the Atlantic Ocean, and the latter is in the western portions of New York and Pennsylvania.

Coastal Region

Salt water occurs naturally in water-table and artesian aquifers along the Atlantic coast. Boundaries between natural fresh water and salty water in the principal aquifers of the Coastal Plain are shown on Figure 36. The fresh-salt water boundaries of the relatively shallow aquifers of

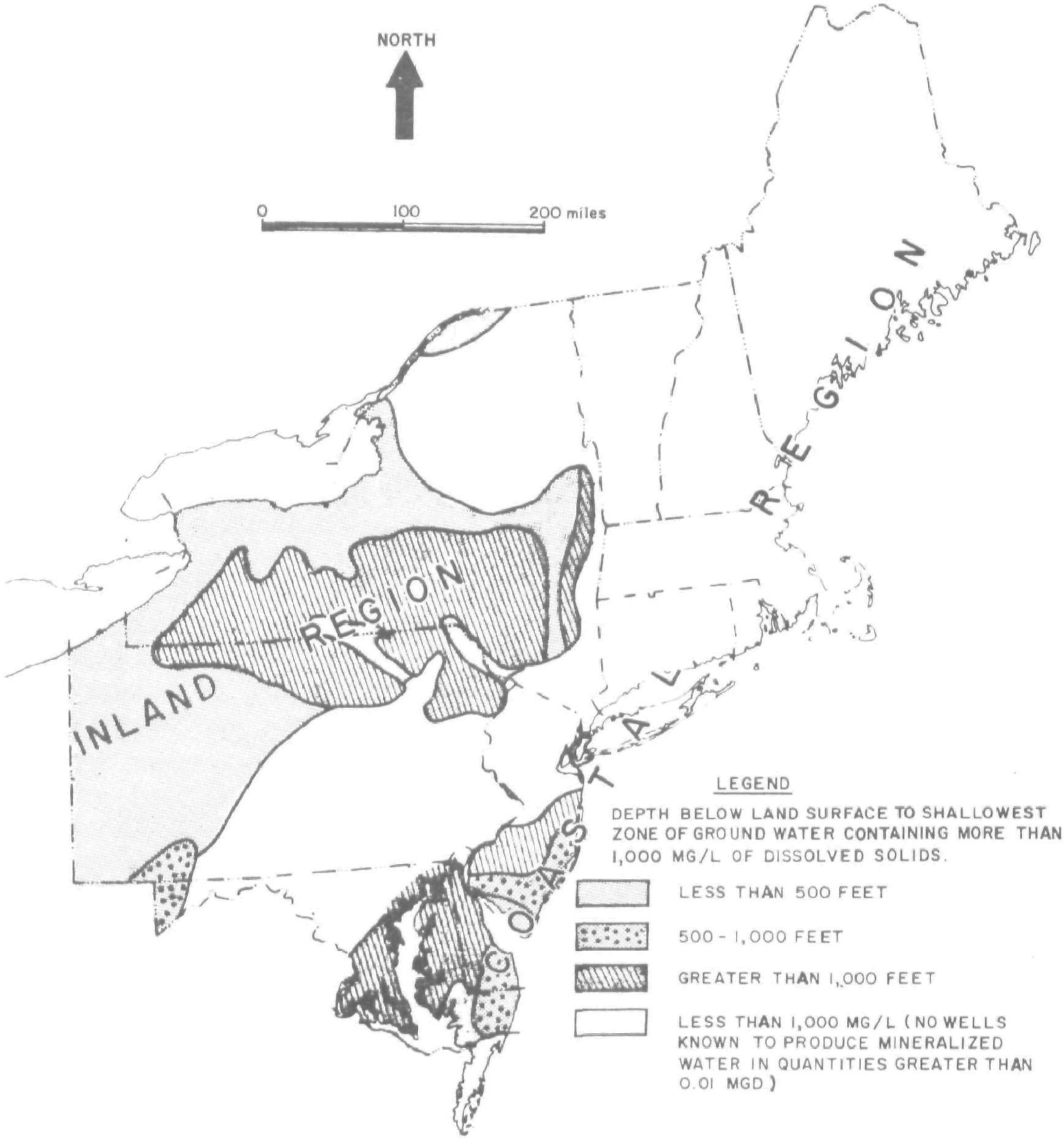

Figure 35. Depth to mineralized ground water in major aquifers in the coastal and inland regions 154)

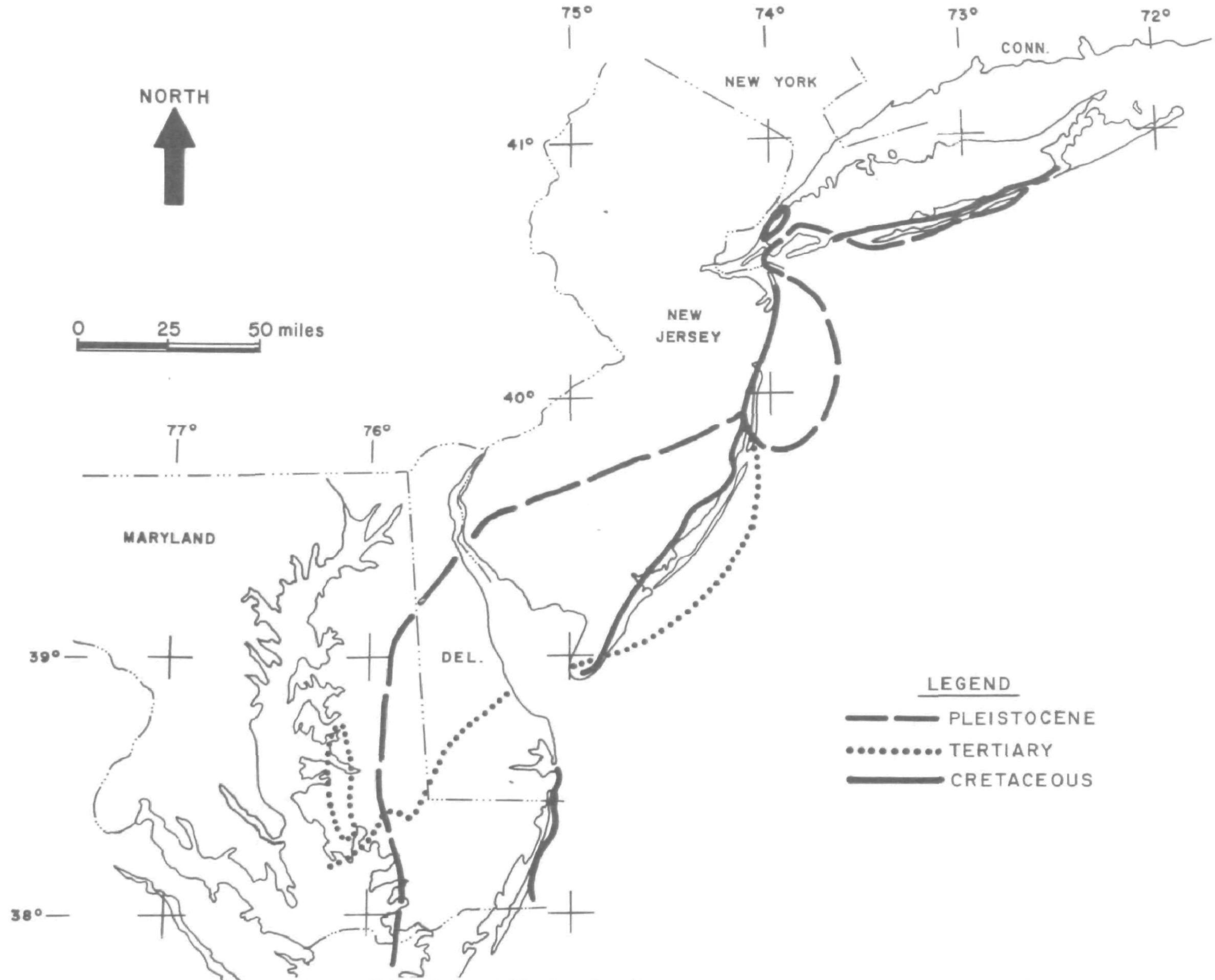

Figure 36. Inland limit of saline ground water in the coastal plain formations of the northeast United States 155)

Pleistocene age correspond closely with the present-day shoreline. However, in some of the deeper aquifers of Tertiary and Cretaceous age, natural salty water occurs many miles from the sea. Also, at some localities near the shore, deep wells may penetrate alternating zones of fresh and salty water.

The Coastal Plain deposits consist of a wedge-shaped mass of unconsolidated rock materials that thickens in a direction roughly perpendicular to the coast of the Atlantic Ocean. The unconsolidated sediments range in thickness from a thin veneer along the Fall Line, which is the western limit of the physiographic province, to as much as 10,000 feet or more along the east coast of Maryland. Aquifers consisting of sands and gravels are areally extensive, underlying hundreds of square miles, and the major aquifer units that have been identified are separated by aquicludes of silt and clay. According to Upson, the seeming anomalies in the pattern of occurrence of salty water in the Coastal Plain deposits are thought to stem from differences in the circulation pattern of fresh ground water in the different aquifers, controlled at least in part by the relationship between intake areas and discharge areas for each aquifer. [154)]

In the glaciated New England states bordering the Atlantic Ocean, salty water is found in the shallow unconsolidated deposits and in the bedrock aquifers along the shoreline and underlying tidal estuaries of the major rivers. No large saline water bodies have been noted that extend many miles inland as in the case of some of the coastal plain aquifers.

Large-scale movement of salt water through an aquifer can occur, displacing fresh ground water, either permanently or temporarily, for a period of time in some cases measured in years. The salt water encroaches into the fresh-water aquifer as a front, which moves laterally. However, in the vicinity of pumping wells tapping a fresh-water zone situated above a salty-water zone, vertical migration of salt water also can occur. Lateral migration is characteristic of salt-water intrusion in the Coastal Plain. In the New England states, salt-water intrusion is characterized principally by small-scale and temporary intrusions of salt-water tongues induced by local pumping from wells constructed close to an existing salt-water body.

Salt-water intrusion occurs as the result of some change in the head relationship between the fresh-water aquifer and interconnected bodies of salt water. The body of salt water in contact with the aquifer may be in a seaward direction or in a deeper section of the aquifer or may be in a tidal portion of a surface stream, bay, or estuary. Pumping from wells lowers the water level in the aquifer and induces the salt-water body to move either laterally or vertically toward the wells. If pumpage is great enough, the decrease in amount of fresh ground water in storage is being compensated for by an increase in the amount of salty ground water in storage. If the pumpage from wells induces recharge from a saline surface-water body, the salty water can enter the fresh-water aquifer and begin to move toward the wells.

One of the mechanisms that can aggravate a problem of salt-water intrusion is leaky or corroded well casings. They can act as an avenue for saline water to migrate from an aquifer containing salt water to an underlying or overlying aquifer containing fresh water. Another is the dredging of a relatively impermeable soils from the bottom of a bay or tidal river. This can result in infiltration of saline surface water to underlying aquifer which is being pumped heavily for water-supply purposes.

The intrusion of salty water into a fresh-water aquifer is characterized by a rise in chloride concentration and total dissolved solids content. For the purpose of this discussion, fresh ground water is defined as water having a chloride content of less than 40 mg/l and generally less than 100 mg/l total dissolved solids. Salty water is defined as water having a chloride content of 40 to about 16,500 mg/l and a total dissolved solids content of about 100 to 31,000 mg/l. Determination of whether salt-water intrusion has occurred in the principal aquifers of the Coastal Region is relatively simple because normal baseline conditions in the fresh-water zones are generally represented by chloride concentrations of less than 20 mg/l.

Case Histories -

Intrusion of salty water is almost always a very slow process. In most heavily pumped areas in the Coastal Region, no contamination has been reported. In some localities where encroachment has taken place, records show that many decades have elapsed before the salt content of the ground water rose to a point where it becomes objectionable. Records also show that the encroachment tends to be restricted to relatively small areas immediately adjacent to the wells that are being pumped. Few cases of broad regional encroachment are known in the study area, and even in those cases, the rate of movement of the advancing salt water is usually only a few feet per year.

For example, one of the most intensively studied salt-water intrusion cases is that involving Coastal Plain deposits in southern Nassau and southeastern Queens Counties, Long Island, New York.[155,156,157)] One wedge of salty water is found in the shallow glacial deposits and two more are in the upper and lower portions of the underlying artesian aquifer. Another artesian aquifer, in which no intrusion has been observed under the land area, lies directly on the bedrock. Figure 37 shows the relationship of the salty and fresh ground-water bodies.

For the most part, the position of the shallow wedge of salty ground water has not changed during historic time. However, the salty ground-water bodies in the underlying artesian aquifer are actively advancing inland in response to pumpage of about 100 mgd from this aquifer. Much of the water pumped is discharged directly to sea from sewage treatment plants, and the consumption of water and the lowering of water levels has led to salt-water intrusion. Nevertheless, it is estimated that the two salty-water wedges in the artesian aquifer have moved inland an average of about 1,000 feet or less since the early 1900's. Locally, in the vicinity of some well fields, the deep salty-water wedge has moved more than a mile inland during the past several decades at a rate of about 300 feet per year.

Table 44 is a summary of data on known ground-water contamination cases in the northeast. It is based on the results of a 1969 survey by the American Society of Civil Engineers Task Committee on Saltwater Intrusion and a review of published and unpublished information on file with regional offices of the U. S. Geological Survey and state geological surveys throughout the study area.[159)]

In spite of the fact that the northeast coastline is more than 1,000 miles in length, relatively few serious problems of ground-water contamination have occurred. One of the principal factors for this, as already mentioned, is the relatively slow lateral movement of salt-water fronts that may be advancing into fresh-water portions of the Coastal Plain aquifers. Another important factor, unlike many other sources of ground-water contamination, is the general widespread knowledge of the positions of salty-water bodies in the region. Considerable research and monitoring of salt-water/fresh-water relationships have been carried out since the early 1930's, and because of the information available, drilling of supply wells in areas prone to salt-water intrusion has been limited. Finally, every state within the Coastal Plain province (New York, New Jersey, Delaware and Maryland) is regulating pumpage from the Coastal Plain

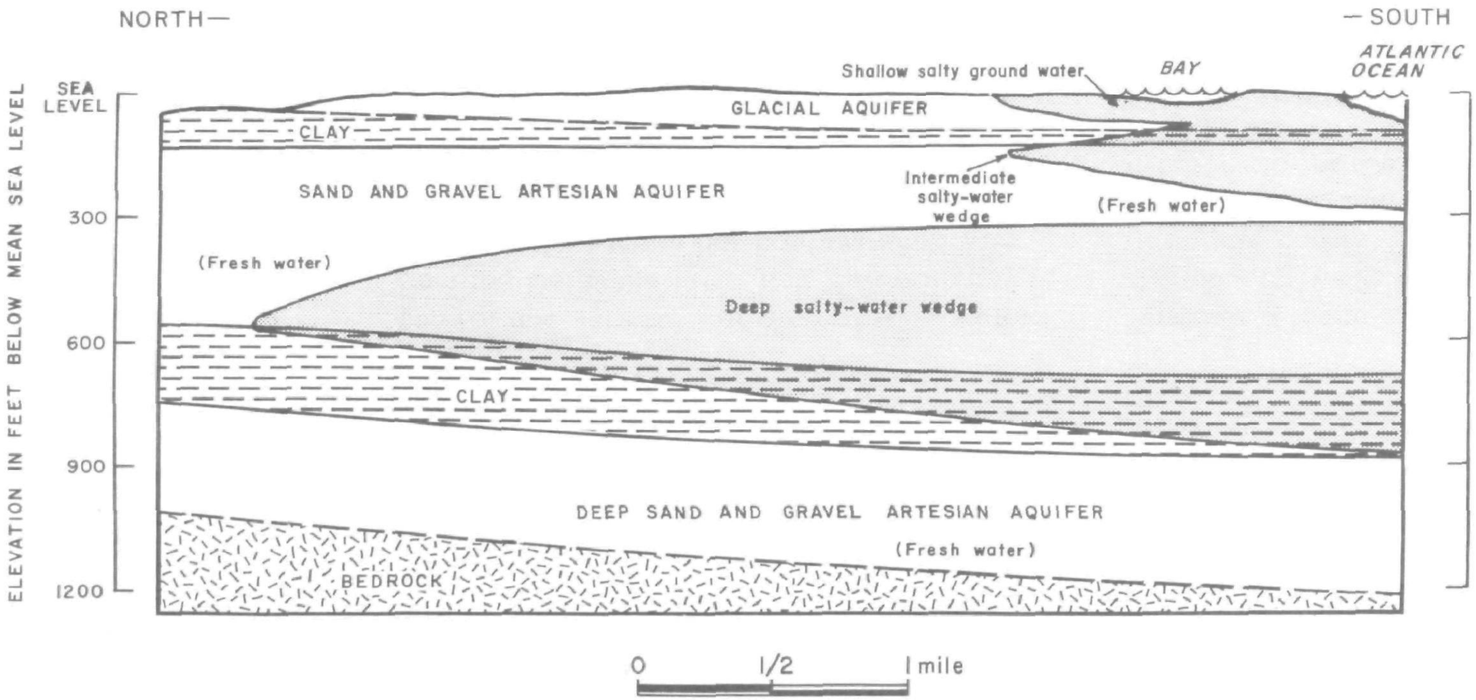

Figure 37. Occurrence of salty ground water in southeastern Queens and southwestern Nassau Counties, Long Island, New York, in 1961 [159]

Table 44. SUMMARY OF DATA ON CONTAMINATION CASES RELATED TO SALT-WATER INTRUSION IN COASTAL AREAS.

Location	Nature of problem	Remedial action
CONNECTICUT		
Long Island Sound coastal area including the Cities of New Haven and Bridgeport	Lateral intrusion of salty water from harbors and tidal river estuaries has contaminated water from several dozen industrial and municipal wells tapping glacial sand and gravel, Triassic sandstone and shale, and crystalline rock aquifers in areas of heavy pumping.	Pumpage relocated inland or reduced; some wells abandoned; and at least one scavenger well installed to hold back salty water.
DELAWARE		
Coastline and Delaware River	Lateral and vertical intrusion of salty water from the Delaware River and Delaware Bay and from the Ocean has contaminated water from three municipal well fields because of intensive pumping from shallow aquifers and the dredging of impermeable soils.	Pumpage relocated inland; wells abandoned; wells deepened; tidal gate constructed to hold back salty surface water in one tributary to the Delaware River.
MAINE		
Town of Bowdoinham, Sagadahoc County	Salty water from tidal reach of Kennebec River has contaminated a well 300 feet deep, tapping the bedrock aquifer.	Well abandoned

Table 44 (continued). SUMMARY OF DATA ON CONTAMINATION CASES RELATED TO SALT-WATER INTRUSION IN COASTAL AREAS.

Location	Nature of problem	Remedial action
MARYLAND		
Harbor District, City of Baltimore	Salty water from Patapsco River estuary has intruded the water table and shallow artesian aquifers.	Many industrial wells abandoned.
Joppatowne, Harford County; and Westover, Sommerset County	Salty water from Chesapeake Bay has been induced into fresh water aquifers tapped by two municipal well fields because of heavy pumpage and leaks in casings of abandoned wells.	Several wells abandoned, others being monitored.
Cambridge, Dorchester County; Annapolis, Anne-Arundal County; and Solomons-Patuxent River area, St. Mary's County	Lateral and vertical intrusion of salty water from tidal river estuaries has contaminated shallow water table and artesian aquifers affecting water quality from numerous domestic and industrial wells. Problem has been aggravated by leaks in casings of abandoned wells.	Abandoned wells are being plugged; pumpage has been reduced; and water quality is being monitored.
MASSACHUSETTS		
Provincetown; Scituate; and Sommerset	Minor lateral intrusion from ocean and salt-water marshes has affected water from wells tapping shallow aquifers.	New wells drilled farther inland; pumpage from old wells reduced.

Table 44 (continued). SUMMARY OF DATA ON CONTAMINATION CASES RELATED TO SALT-WATER INTRUSION IN COASTAL AREAS.

Location	Nature of problem	Remedial action
NEW HAMPSHIRE		
Portsmouth	Minor lateral intrusion from tidal water in Piscataqua River.	Unknown
NEW JERSEY		
Sayreville, Middlesex County; Gibbstown-Paulsborough area, Gloucester County; Newark, Essex County; Rahway area, Union-Middlesex Counties; Salem, Salem County	Salty water from tidal estuaries and bays has intruded water table and artesian aquifers due to intensive pumping and harbor and canal dredging	Pumpage relocated inland; and many wells abandoned.
Atlantic City, Atlantic County; and several areas in Cape May County	Salty and brackish water from saline-water aquifers has intruded shallow and deep fresh-water aquifers due to heavy pumping and corroded well casings. Problem mostly local in nature	Pumpage has been reduced in a few wells; wells with leaky casings have been sealed; and new, double-cased wells have been drilled into the artesian aquifer. Some tidal gates have been installed.
Sommers Point, Atlantic County	Wedge of salty water has moved about 3,000 feet landward into the Cohansey aquifer.	Pumpage has been reduced; monitoring; new wells are planned inland.

Table 44 (continued). SUMMARY OF DATA ON CONTAMINATION CASES RELATED TO SALT-WATER INTRUSION IN COASTAL AREAS.

Location	Nature of problem	Remedial action
NEW JERSEY (continued)		
Artificial Island, Salem County	Salt-water intrusion at nuclear generating plant.	Pumpage has been concentrated at southern end of island where aquiclude is thickest.
NEW YORK		
Kings County, Long Island	Salt-water intrusion resulting in severe contamination of glacial aquifer due to lowering of water table below sea level over a broad area.	Pumpage reduced; all public and many industrial water-supply wells abandoned; artificial recharge of cooling water required.
Queens, Nassau, and Suffolk Counties, Long Island	Lateral and vertical intrusion of salty water from ocean into the water table and artesian aquifers, but only immediately adjacent to shorelines. Problem caused by pumping, leaky well casings, and dredging.	Pumpage near shorelines reduced; ground-water diversions under strict control; artificial recharge of cooling water required.
PENNSYLVANIA		
Philadelphia	Lateral intrusion of salty water from the tidal Delaware River has contaminated industrial wells in the shallow aquifer due to pumping. Leaky well casings and dredging the Delaware River has aggravated the problem.	Some industrial wells abandoned.

Table 44 (continued). SUMMARY OF DATA ON CONTAMINATION CASES RELATED TO SALT-WATER INTRUSION IN COASTAL AREAS.

Location	Nature of problem	Remedial action
RHODE ISLAND		
City of Providence; Town of Barrington	Salty water from tidal river estuaries and bays has contaminated water from some municipal wells tapping the glacial outwash aquifer due to heavy pumping.	Pumpage has been reduced, the ground-water supply may be replaced with surface water.

aquifers. These regulations, which involve complete control over rates and patterns of pumpage from proposed significant ground-water diversions, were prompted to a great degree by the recognition of the need for management of water resources in areas subject to salt-water intrusion.

Although serious problems of ground-water contamination are not numerous, the presence of salty water in coastal aquifers throughout the region has a limiting effect on the availability of ground water. Well diversions must be kept within certain limits in order to maintain salt-water fronts in as much of a status-quo position as possible, which is the present philosophy of regulatory agencies in the region. In fact, in order to aid in reducing the threat of contamination from this source, artificial recharge of cooling waters and storm waters has been encouraged in Long Island, New York and in some parts of New Jersey. There are more than 1,000 recharge or diffusion wells returning used ground water to the aquifers underlying Long Island. 160) In 1965, an average of about 77 mgd was injected, mostly cooling water used for air conditioning. In addition, there are more than 2,000 recharge basins in Nassau and Suffolk Counties ranging from about 10 to 20 feet in depth and from about one to 30 acres in size. The basins are unlined excavations which receive storm-water runoff from streets and highways.

A method used in the region to limit encroachment of saline surface water inland in rivers and streams, in areas where salty surface-water intrusion into underlying aquifers might occur, is the installation of tidal gates. These structures hold back saline water from flowing upstream during high-tide periods. A number of tidal gates have been placed across small coastal streams in Cape May County, New Jersey, for example. 161) Relief wells have also been installed in a few locations. The purpose of these wells is to pump salt water, thereby lowering the head in the saline ground-water body and retarding or preventing movement of saline water toward wells pumping from a fresh-water zone.

<u>Future Trends</u> -

Because of the close regulatory control over diversion of ground water near coastal regions in some of the states and the general knowledge of where saline ground-water bodies might be encountered in most of the states, it is unlikely that the number of problems of contamination from this source will rise significantly in the near future. However, one possibility that might lead in the future to the establishment of new positions farther inland for salt-water fronts in some areas is a change in water-management attitudes. These changes might occur in response to greater demands for water-supply development because of continuing population growth in coastal areas.

The landward extent of a wedge of salty water is controlled by the rate at which ground water is discharging from the aquifer into the ocean. Some of the counties within the Coastal Plain area may become water-short in the near future and the decision will have to be made on how to meet increased water needs. One alternative, of course, is the importation of surface water into those areas presently dependent upon ground water. Another alternative would involve abandoning the present management concept of maintaining salt-water fronts in a status-quo position, withdrawing more fresh ground water for consumptive use, and permitting salt water to move inland to a new position of stabilization. The replacement of wells contaminated and lost in the process may be considerably less costly than importing surface water or some other alternative that might be proposed for solving water-supply needs. A technical-economic evaluation of the feasibility of removing more ground water from storage would be of considerable aid to water planners in the Coastal Region.

Inland Region

Little information has been collected and analyzed, or published, on salt-water intrusion in the Inland Region of New York and Pennsylvania. Natural saline water occurs at depth in consolidated rock formations. However, these areas are usually overlain by aquifers containing fresh water. Saline water also has been encountered in unconsolidated glacial deposits in some locations that are discharge areas for mineralized ground water originating in the rock formations. As in the Coastal Region, saline water tends to move toward wells when the fresh-water head is reduced by pumping. Vertical rather than lateral encroachment is more characteristic of the Inland Region. The presence of natural saline water may be related to one or more of the following causes: retention in the rock formation of the salty water in which the formation was deposited (connate water); solution of salt from the formation itself or from adjacent formations; and entrance of salt water into the formation after it was deposited and subsequently exposed to another source of salt water. 162)

Because of the widespread and complex occurrence of saline water in the region, it can be difficult to determine whether salt-water intrusion has occurred or whether poor quality water yielded by a particular well is the result of natural conditions. In addition, unlike the Coastal Region where fresh waters are only slightly mineralized, ground water can be considered "fresh" by well owners in the Inland Region and have high concentrations of hardness, sulfates, chlorides, and dissolved solids.

Figure 38 illustrates how variations of chemical quality can occur in ground water as a result of natural recharge and discharge relationships. In the uplands, recharge from precipitation reaches the water table and becomes ground water. Some of the ground water travels through deeper rock zones; comes in contact with carbonate, sulfate, and chloride minerals, which are taken into solution; and ultimately discharges to the unconsolidated deposits in the valley. If wells are being pumped in the valley, the salinity of water in the sand and gravel aquifer may be increased because of vertical intrusion of a higher percentage of saline water from deeper, more highly mineralized zones. Figure 39 shows how local ground-water circulation can produce a relatively thin fresh-water zone above salt water. Heavy pumpage in this situation from wells tapping the shallow deposits can produce vertical salt-water intrusion. It should be noted that Figures 38 and 39 are only two examples of many types of different conditions that could be encountered in various parts of the Inland Region.

The natural occurrence of saline water and the potential for salt-water intrusion are limiting factors on the development of ground water. Some regional investigations of ground-water resources have been carried out by federal and state agencies, and as more are completed, the nature and occurrence of saline water will become better defined. Because of this, problems of salt-water intrusion should be more easily avoided through proper well location and construction. Governmental controls over diversions of ground water in the Inland Region, as a protective measure against salt-water intrusion, do not exist and would be difficult to enforce until the problem is better defined by additional area-wide studies.

RIVER INFILTRATION

Throughout the northeast, rivers and lakes are a major source of recharge to high capacity public supply and industrial water wells. Where a surface-water body is hydraulically connected with an aquifer, pumping from wells and the resulting drawdown of water levels in the aquifer can induce surface water to infiltrate through the stream bed and into the ground-water reservoir. This infiltrated water can then migrate to the pumping wells. Studies of the relation-

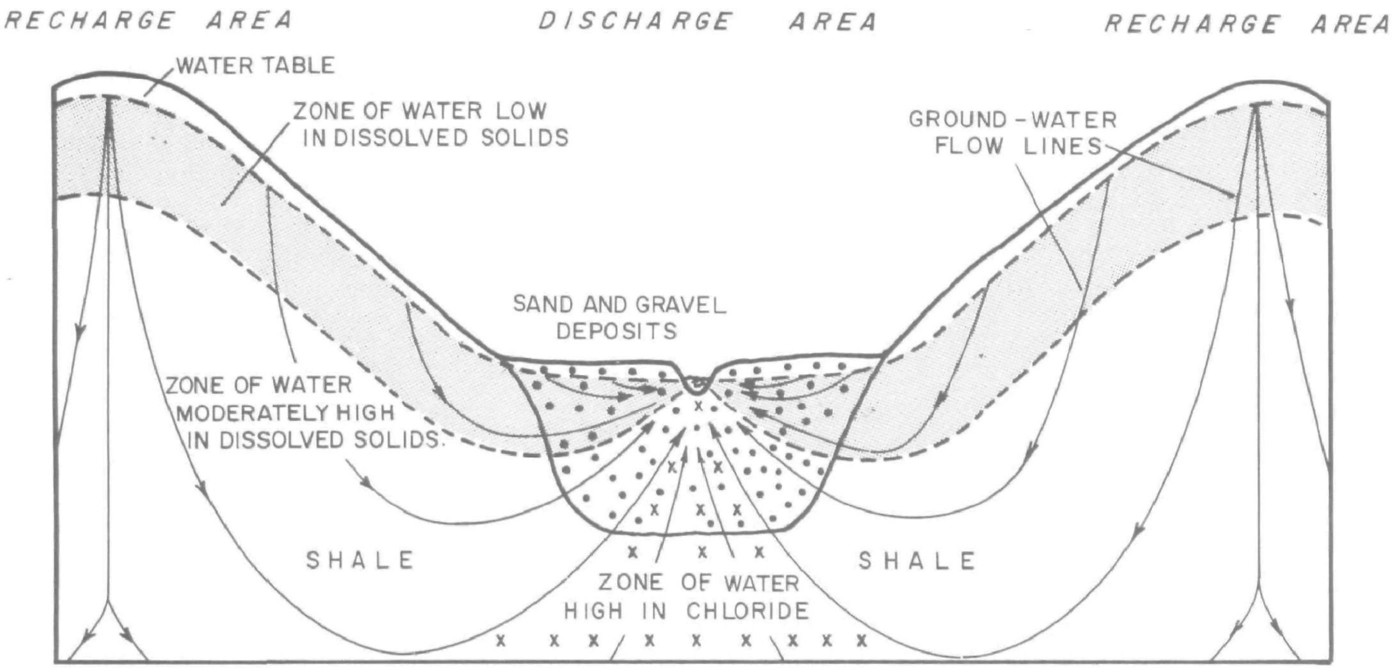

Figure 38. Variations of chemical quality of ground water as related to recharge and discharge relationships [164]

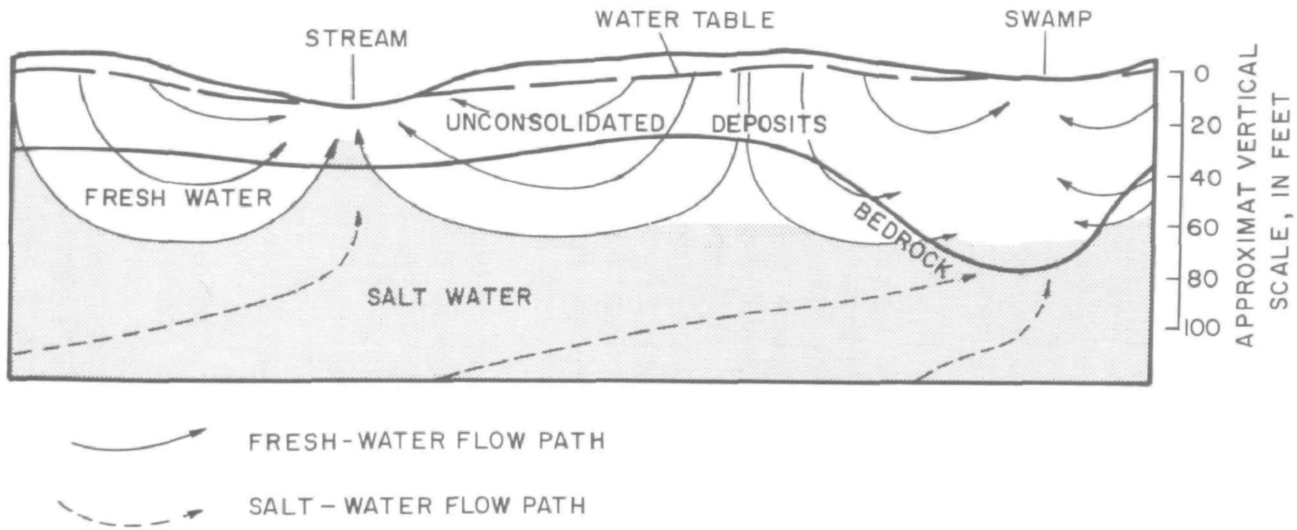

Figure 39. Local ground-water circulation, producing a relatively thin fresh-water zone above the salt water 165)

ship between surface water and ground water have shown that wells drilled within a few hundred to as much as a thousand feet away from rivers and lakes can yield a high percentage of water derived from infiltration. For example, pumping tests conducted along the Delaware River in the vicinity of Camden, New Jersey, indicate that, at a pumping rate of six mgd from one major field, about 60 percent of the well water is derived from river infiltration and only 40 percent from ground-water storage.[165)] Discussions with water-well drillers, municipal water works operators, and representatives of state agencies indicate that infiltrated surface water pumped from wells in the study region amounts to many hundreds of millions of gallons per day. Individual well capacities range from one-quarter of a million to as much as six mgd.

If the infiltrated water passes through a large enough volume of soil and aquifer materials before arriving at the pumping well, natural filtration, adsorption, and ion exchange can take place. Turbidity, organic materials, pathogenic bacteria, and some chemical constituents can be effectively removed or reduced. Thus, high-quality ground-water supplies can be developed adjacent to many poor-quality streams. This feature of infiltrated ground water plus the large amount of potential recharge available from major streams have made the development of wells adjacent to surface-water bodies very attractive to water-works operators.

Unfortunately, few investigations have been made to determine whether trace amounts of such pollutants as heavy metals, organic compounds and viruses can migrate through aquifer materials to pumped wells. In a few cases, bacteria have been known to survive infiltration from the surface-water source to the well. Also, acid or reducing surface waters that come in contact with some aquifer materials can dissolve iron and manganese that naturally occur in a precipitated form in the sediments. This action has resulted in a build-up of iron and manganese in the well water and has required the construction of treatment plants for reduction of these constituents. In some instances, iron and manganese concentrations have been great enough to result in abandonment of the well supply.

Case Histories

Several documented case histories in the study area illustrate some of the problems of ground-water contamination that can occur from surface-water infiltration. For example, infiltrated water from a polluted tributary of the Hudson River dissolved iron and manganese in the natural sand and gravel sediments tapped by a high capacity caisson well in southeastern New York.[166] Analyses of water from the stream had never shown high levels of manganese, but the surface water was contaminated with wastes from two paper mills, a textile plant, and several sewage treatment plants. The aquifer consists of manganese-rich debris from glacially eroded crystalline rock.

Manganese concentration in water from the caisson well, which was capable of producing several mgd, rose from less than one mg/l when the well was first drilled to more than 14 mg/l after several months of pumping. Tests at the site definitely established that a major portion of the water pumped from the caisson well was derived from infiltration from the stream. Water temperature in the well varied according to the water temperature of the tributary and the manganese content of water from an observation well located halfway between the stream and the caisson well rose and fell in direct relation to the amount of induced river water. Even though the caisson well is 100 feet from the stream, high counts of coliform bacteria were detected in the ground water, and it was concluded that the source of this contaminant was also related to infiltration of the surface water. No means were found for diverting the polluted surface water away from the well without reducing its yield to an unacceptable level. Treatment for the high concentration of manganese was considered to be uneconomic, and the well was abandoned.

In a case in Connecticut, a six-mgd well field was developed adjacent to the Connecticut River. Again, the reducing environment created by the infiltrated river water moving through iron-rich unconsolidated sediments resulted in a water-quality problem.[167] Pumping tests at the site revealed that production wells capable of producing two mgd each and located 150 feet from the bank of the river were recharged with up to 90 percent induced infiltrated surface water and with only 10 percent ground-water storage. Figure 40 shows the relationship between pumping from one of the test wells and changes in iron and hardness concentrations. The initial total hardness (as $CaCO_3$) of the well water ranged from about 120 to 160 mg/l. The initial concentration of iron was less than 0.1 mg/l. Concentrations of hardness and iron in the Connecticut River adjacent to the site averaged 44 and 1.0 mg/l respectively. The diagram shows that during periods of pumping, the iron content rose in the well water and stabilized at a level similar to that found in the river. Meanwhile, the concentration of hardness in the well water declined to a level of 80 mg/l. An iron-treatment plant was constructed at the site so that the

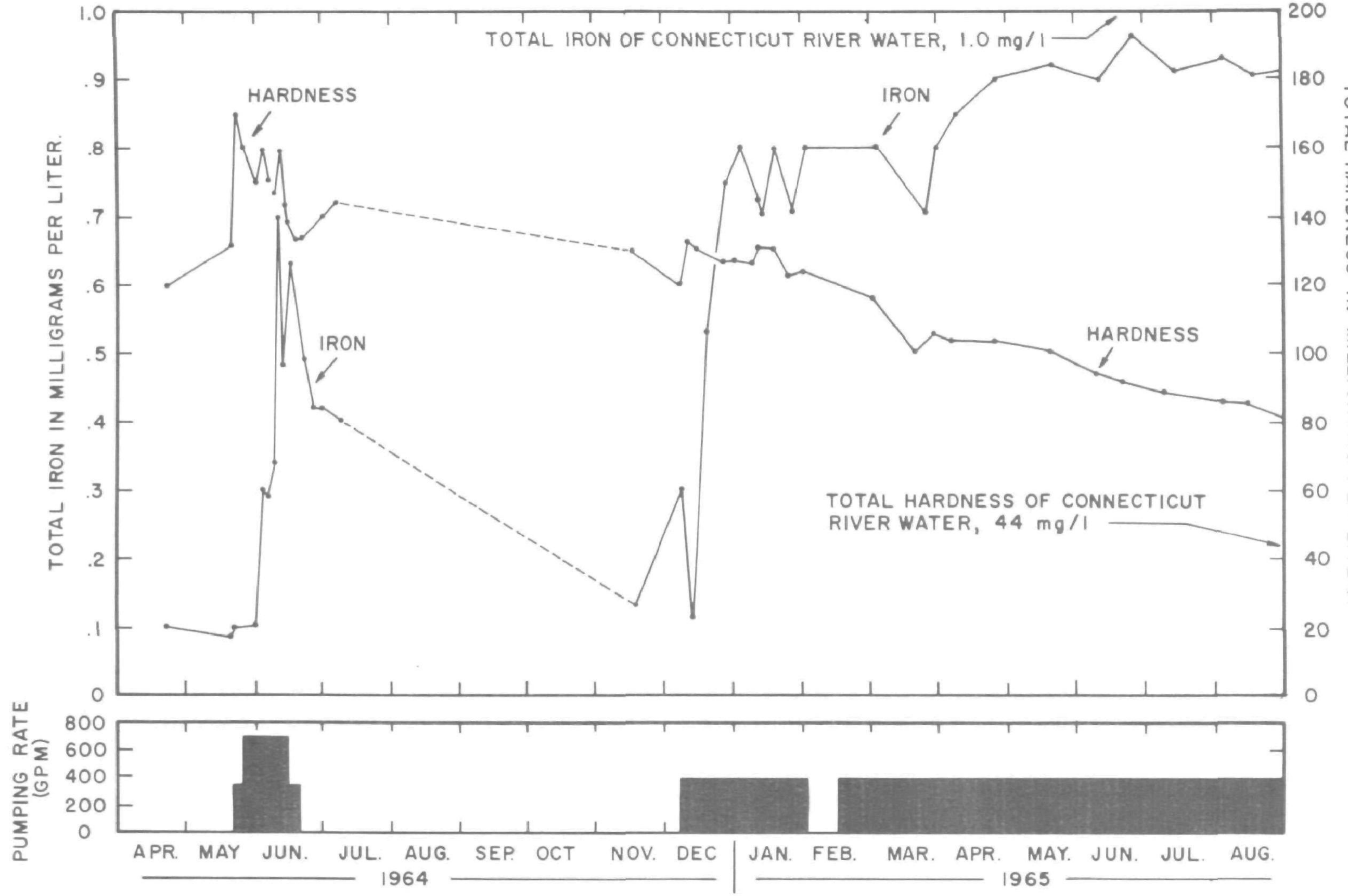

Figure 40. Effect of infiltration of Connecticut river water on quality of water from test production well 168)

ground water could be used for public supply.

A public-supply well in Onondaga County, New York, has occasionally yielded water with high concentrations (0.15 mg/l) of lead.[81] The source of the pollutant is concluded to be a river several hundred feet away, which provides a major portion of the recharge to the well. The amount of the pollutant reaching the well during any given period depends on the character of industrial discharges to the stream and its flow stage.

Future Trends

Cases similar to those described above involving iron and manganese are very common throughout the northeast. However, in spite of the cost for treatment brought about by this type of problem, the development of ground water as compared to surface water is still economically favorable. The drilling of wells recharged by rivers and lakes will continue, and infiltrated ground water will remain as a vital source of supply for municipalities and industries.

Unfortunately, few detailed chemical analyses are available for water from wells which depend on a high percentage of recharge from polluted streams. More information is needed on the fate of such trace substances as heavy metals and organic compounds in waters that are infiltrated from rivers and lakes. Herbicides and pesticides, for example, can concentrate in bottom sediments of surface-water bodies, and data are lacking on whether these substances can be leached by surface waters induced into underlying aquifers. In addition, many of these ground-water supply systems have been in operation for many years. Conceivably, the ion exchange and adsorptive capacities of the aquifer sediments for removal of potential pollutants may be nearly exhausted. Information is lacking on the ability of various types of sediments to treat infiltrated surface water and the time factors involved.

Health agencies in the region generally rely on maintaining an arbitrary distance between the well supply and the surface-water source as a safeguard against ground-water contamination. Also, codes covering well construction call for sealing the well against possible leakage of surface water along the annular space outside the casing and require the site to be protected against flooding from the nearby stream. Pumping tests of up to five days are another requirement, the purpose of which theoretically is to provide enough data for determination of the effects of infiltrated surface water on ground-water quality.

Because of the highly complex geologic and hydrologic conditions that occur in the study area, especially in the glaciated portion, these safeguards may not be adequate. The ability for surface water to infiltrate to high-capacity wells varies greatly from place to place. For example, a uniform distance of 200 feet for wells located near two polluted streams of similar quality may be safe in one instance but not in the other, depending on the percentage of surface water infiltrated, the time of travel for a drop of infiltrated surface water to migrate from the bottom of the stream bed to the well screen, and the ability of the sediments in the aquifer to modify the quality of the surface water. Weeks, and in some cases months, of pumping may be required for a detectable volume of infiltrated surface water to reach a particular well. Only then can a proper judgement be made on long-term water-quality relationships between surface water and ground water.

Regulation of well development adjacent to streams should be based on a more specific and technical analysis of hydraulic and water-quality conditions at each particular site under consideration. In some cases, ground-water supplies that may be perfectly safe for public consumption are not being developed because they do not meet arbitrary requirements set by regulatory agencies. At other sites, the parameters are being met but may not be protective enough.

One problem that appears to be quite common to infiltrated ground-water supplies containing high concentrations of iron is the growth of iron bacteria in water from wells after some period of use. Little is known about the cause of this phenomenon, for example whether the bacteria originates in the aquifer as a result of the addition of trace amounts of organic matter due to infiltration of surface water or whether it may be related to conditions in the particular water-supply distribution systems. Also, long-lasting methods for cleaning up this form of contamination have not been developed.

UNDERGROUND STORAGE AND ARTIFICIAL RECHARGE OF WASTE WATER

Waste water is purposely disposed of or recharged to the underground in the northeast region in a number of different ways. Discharge of sewage effluent to septic tanks and cesspools is the most common method and is discussed separately in another portion of the report. Other means of disposal include deep wells drilled into saline aquifers, shallow wells discharging into fresh-water aquifers, pits and basins for rapid infiltration, and spray irrigation. Each of these is discussed separately in the following paragraphs.

Deep Disposal Wells

Disposal of industrial wastes in saline aquifers through wells more than 1,000 feet deep has been practiced in only two of the states of the study region, New York and Pennsylvania. Four injection wells have been constructed in New York and nine in Pennsylvania.[168,169] To date, only one of the wells has ever been placed into operation in New York. In Pennsylvania, all but perhaps one or two of the original nine injection wells have been shut down.[169]

Most of the wells have not been put into operation or have been abandoned because of difficulties in the physical operation of the system. One 1,600 foot-deep injection well did fail in Erie, Pennsylvania, in 1968.[170] Apparently, after four years of operation during which approximately 55,000 barrels per day of spent sulfite liquor containing fiber, titanium dioxide, clay, and lignin-like compounds were pumped into the well under pressure, the injection tubing corroded, and the pressure was released to the outer well casing. It is not known whether shallow fresh-water aquifers were contaminated, but a considerable volume of the pollutant was discharged into Lake Erie.

Few if any new industrial-waste injection wells will be constructed in the region in the foreseeable future. Interviews with representatives of environmental agencies in the 11 states covered by this report revealed a very negative attitude toward deep well disposal. The principal reason given is that geologic conditions are not considered to be favorable for the safe disposal and storage of chemical wastes underground. In most states, a proposal for deep disposal of industrial wastes would not even be considered. In others, rigid constraints imposed by regulatory agencies would most likely rule out consideration of such an alternative for waste disposal.

Shallow Disposal Wells

Shallow wells, less than 1,000 feet deep, completed in fresh-water aquifers are used in the northeast to dispose of a variety of liquid wastes including storm water, sewage, cooling water, and industrial effluent. They can be constructed for the specific purpose of injecting the fluid under controlled conditions, sometimes under pressure, or they simply can be abandoned water wells converted to receiving waste water. Public agencies in some portions of the study region have encouraged experimentation with or use of shallow wells for disposal or recharge of storm-water runoff from streets and buildings, unadulterated cooling water from air conditioners, and tertiary-treated sewage effluent. Although shallow wells recharging fresh-water aquifers with untreated sewage effluent or industrial waste water exist, they are considered to be illegal throughout the region.

The type and degree of contamination of fresh ground-water aquifers that can occur as a result of waste-water recharge through wells depends, of course, on the source of the pollutant. For example, storm waters can contain high levels of BOD, COD, nitrates, phosphates, chlorides, and heavy metals. [69] The injection of heated waste waters from air cooling systems can raise ground-water temperatures.

Case Histories -

Storm-water runoff from paved areas at industrial sites, airports, and roadways is sometimes collected in dry wells, which consist of perforated or porous concrete rings set in a hole usually dug five to 10 feet below land surface or to the top of the water table. If the water contains fertilizers, pesticides, and insecticides used on lawns in a housing development, or a high level of chlorides from application of deicing salts, contamination of the shallow aquifer can occur in the vicinity of the disposal well. The injection of drainage water, and possible injection of industrial wastes through disposal wells has produced some ground-water contamination in the Buffalo, New York, area. [163] Use of dry wells or "sumps" is common in suburban Long Island, New York. The wells are placed in parking lots at apartment, office, industrial and shopping center complexes, or in cloverleafs of housing developments, to collect and dispose of runoff. Tens of thousands of dry wells are probably used throughout the region for a similar purpose. However, their construction is not normally supervised by public agencies and their locations in any particular area are unknown.

Controlled experiments involving injection of municipal sewage wastes have been carried out in at least two locations in the study region. A major research project in the treatment and injection of renovated water has been underway for a number of years at Bay Park in Nassau County, New York under the direction of the U. S. Geological Survey. [171,172] Tertiary-treated sewage has been injected periodically at a test rate of as high as 350 gpm into a fresh-water zone of the Magothy aquifer at a depth of 418 to 460 feet below land surface. Data are being collected to determine the feasibility of this method for replenishment of the aquifer.

The second experiment involved disposal of filtered sewage from the Town of Riverhead, Suffolk County, New York, into shallow wells screened in the glacial outwash. [173] Considerable plugging of the well screens was encountered, and the system has not been adapted to permanent use.

Instances of uncontrolled disposal of domestic wastes to wells that have led to recorded cases of ground-water contamination include one in Berks County, Pennsylvania, in which it was discovered that sewage from a number of houses was being discharged into wells about 100 feet deep. [174] It is feared that both the unconsolidated and consolidated aquifers in the area have been contaminated. In several villages in Connecticut, water softener effluent discharged into dry wells at apartment buildings has raised chloride and sodium concentrations in water from nearby domestic wells tapping shallow glacial deposits. [175]

Since 1933, New York State has required the return to the ground of water pumped for industrial air-conditioning purposes "in an uncontaminated condition through diffusion wells or other approved structures." [176] The regulation covers all new industrial wells with capacities in excess of 100,000 gpd. The term "diffusion wells" actually refers to a recharge or injection well, and they have been used almost exclusively for disposing of waste water from air conditioning or cooling systems. Estimates are that 1,000 such wells, screened in the glacial and Magothy aquifers of Long Island, are in operation today and inject about 80 mgd of heated water into the subsurface. [160] Reports of problems related to thermal pollution of ground water in Long Island are not numerous, but as far back as 1937, an investigation in Kings County noted a rise of 14°F in the sediments surrounding a diffusion well in the shallow glacial aquifer. [158] The well injected about one mgd of cooling waste water from an ice manufacturing plant. Natural temperature of shallow ground water on Long Island is 52° to 56°F. The temperature of the recharge water was about 83°F. A few wells in other parts of Kings County have yielded water with temperatures about 80°F. [177]

In New Jersey, protection of ground-water diversion rights in critical areas of the state has encouraged recharge of waste cooling water from air conditioning systems at commercial and industrial sites rather than disposal of the waste water to sewers. Normally, the only form of pollution is a rise in temperature because the ground water is circulated through a closed system and chemicals for corrosion control are not added to the cooling water. Whether enough recharge wells of this type have been drilled in urbanized areas of New Jersey to locally modify the normal ground-water temperature of about 52°F has not been investigated.

Use of wells completed in fresh-water aquifers for disposal of industrial wastes is probably rare in the region. However, one case that came to light in Pennsylvania a few years ago is worthy of note. Plating wastes that were being injected illegally through shallow wells contaminated a limestone aquifer. 178) The principal pollutant is hexavalent chromium. Water from public-supply wells several thousand feet away were affected before the source of contamination was discovered and eliminated.

Future Trends -

Recharge of waste water through shallow wells will probably not be an important source of contamination in the northeast in the future except in the case of dry wells used for disposal of storm-water runoff and recharge wells used to inject waste cooling waters. Such waters generally are not considered as sources of contamination to ground water. However, more controls are needed to guard against use of dry wells and recharge wells for disposal of waters that may contain chemical pollutants originating from industrial processes. Furthermore, runoff from highways, roadways, parking lots and lawn areas can contain fertilizer, salt, pesticide, and other organic and inorganic residues. Research is needed to determine the effects of these substances on ground-water quality in urban areas.

Additional research on well-construction techniques and water renovation is needed to solve current problems of plugging of screens and clogging of aquifer materials before disposal of treated sewage effluent in shallow wells can be widely practiced. The New England River Basins Commission in their 1973-1974 Long Island Sound Regional Study has concluded that technological capability for recycling treated waste water into underground supplies will not be available before 1985. 179) Industrial-waste water is regarded by regulatory agencies as too hazardous for injection into fresh-water aquifers because of the hazardous materials that may be contained in the effluent, and injection will continue to be prohibited.

Recharge Basins

Recharge basins are used in the region to dispose of storm-water runoff, industrial and commercial wastes, and treated sewage. They are unlined rectangular excavations up to 20 feet deep, and they range in size from a few thousand square feet to more than 10 acres. Where rapid infiltration is desired, or the water table is shallow, basins are sometimes constructed partially or completely above ground within a set of dikes in order to raise the head of the recharge water.

Probably the greatest density of recharge basins in the study area is on Long Island, New York, where more than 2,000 are used for disposal of storm-water runoff and about 200 for discharge of industrial and commercial wastes. It is estimated that in 1966 about 100 mgd was recharged to shallow aquifers through the storm-runoff detention basins and about 30 mgd through the 200 industrial and commercial basins.[180] Principally as a conservation measure to insure continued replenishment of the aquifers underlying Long Island, most new housing and industrial developments in Nassau and Suffolk Counties have been required over the past two decades to include the construction of one or more basins, depending on the size of the drainage area involved. In addition, much of the runoff from highways and streets on Long Island is collected in recharge basins. Industrial and commercial waste water disposed of in recharge basins on Long Island generally is derived from cooling systems and thus heat is the only pollutant.

The use of recharge basins for rapid infiltration of treated municipal sewage effluent is not widely practiced in the region. However, interest in this method of disposal is growing because of stricter regulation of waste discharge to surface streams. For example, in New Jersey, rapid infiltration of municipal waste that has received at least secondary treatment has been approved by regulatory agencies over the past few years in a number of cases where disposal to surface waters available to the treatment plant has been ruled out because of enforcement of a stream water-quality classification system. In these cases, use of septic tanks was also ruled out because individual lot sizes were too small or the projected flow rate was too high.

In New York, rapid infiltration of municipal sewage wastes dates back to 1936 at the Lake George Village treatment plant. Altogether, about a dozen other municipal systems in the state are recharging through leaching pits or sand filters. Average flow rates are relatively small, with none exceeding one mgd.[181] Massachusetts has another relatively old rapid infiltration system at Fort Devens, where treated sewage effluent has been recharged underground for about 30 years.[182]

Because of the general lack of monitoring of ground-water quality at such sites, it is not known what effect recharging of treated sewage has over the long term. Certainly concentrations of nitrates are raised, along with those of chlorides and perhaps other minerals, in the immediate vicinity of the recharge basins, but how extensive this contamination is under different conditions of soil, geology, and hydrology is unknown. Nevertheless, as an alternative for domestic waste disposal, rapid infiltration probably compares favorably with the use of septic tanks at many locations because the sewage can be treated to some degree before it is discharged underground.

Spray Irrigation

Spray irrigation has been defined as "the controlled spraying of liquid onto land at a rate measured in inches of liquid per week with the flow path being infiltration and percolation within the boundaries of the disposal site." 183) Within the northeast region, spray irrigation has been applied to both forested sites and agricultural lands. The method has been used to dispose of municipal or domestic wastes from small communities, housing developments, and recreational areas. It has also been used for the land treatment of some industrial wastes, principally from food processing. As in the case of rapid infiltration of sewage effluent discussed above, the percentage disposed of through spray irrigation is small as compared to the overall discharge of waste effluent in the region. However, interest and activity in the application of spray irrigation is growing, again because of stricter controls over discharge of sewage and industrial wastes to surface streams.

Although information is limited on the location and operation of existing spray irrigation systems, discussions with representatives of public agencies in the region indicate that the practice is carried out in a limited way or experimentally in every one of the 11 states. Information for those sites for which data has been collected indicates that the average rate of disposal of wastes is generally less than one mgd. However, there are exceptions. For example, the Hunt-Wesson Foods Corporation in Bridgeton, New Jersey, reportedly spray irrigates three mgd, and the H. J. Heinz Company in Salem, New Jersey, periodically spray irrigates 1.3 mgd. Both involve application of wastes from food processing. 183)

The spray-irrigation system that has received the most research is the one in operation at State College, Pennsylvania. 184) At this site, personnel from the Pennsylvania State University have been studying such factors as infiltration capacity of the soil, effects of climate, and the ability of the land to treat domestic sewage effluent. Studies are continuing and include the collection of information on long-term effects of spray irrigation of waste water on ground-water quality.

Because of the general lack of monitoring and/or the evaluation of data collected from monitoring wells, little is known at present with regard to the relationship between high rates of sewage application to the land and the ability of the soils to render the effluent harmless. However, data on two cases of ground-water contamination related to spray irrigation were collected in this survey. One involved a well supply that became contaminated with a phenolic material from spray irrigation of organic wastes from a chicken processing plant in Maryland.[185)] The other involved contamination of a limestone aquifer in Pennsylvania caused by spraying and lagooning of phenolic materials and solvents from chemical industries. In this latter case, a contaminated zone 4,000 feet long and 300 feet wide was formed in the shallow aquifer. Spray irrigation has been halted and the waste lagoons have been lined.[141)]

Because of the large land area normally required for this method of disposal of municipal wastes, use of spray irrigation will probably continue to be limited to small communities and individual industries. More information is needed, based on monitoring of existing sites, in order to determine whether spray irrigation represents a significant source of ground-water contamination. Two states in the study region, Pennsylvania and Vermont, have prepared manuals on site selection and system design for spray irrigation.[186,187)] As interest in this process increases, other states in the region will probably develop similar standards. Considerable additional research is needed on the effects of the various types of wastes proposed for land application so that future problems related to degradation of ground-water quality can be avoided.

WATER WELLS

Water wells themselves are not normally sources of ground-water contamination except where a casing has been corroded or ruptured, where well screens or the open borehole interconnects two separate aquifers, or where the surface casing has not been adequately sealed in soil or rock. In these instances, water wells can serve as a means for transmission of pollutants from one aquifer to another or from the land surface to an aquifer.

One of the most common problems related to this source of contamination is the vertical movement of saline water into a fresh-water aquifer. In a number of the cases of salt-water intrusion listed in Table 44, the contamination of the fresh-water aquifer was aggravated by the presence in the area of numerous abandoned and corroded well casings, which allowed saline water to enter the fresh-water aquifer either from an overlying or underlying saline-water aquifer or from an adjacent salty surface-water body. Probably the most classic case of this type of contamination has taken place in Baltimore, Maryland.[188)] Contamination of ground water by industrial waste was first recognized in the late 1800's when it was reported that soils in the heavily industrialized districts of that coastal municipality were saturated with acid from metal processing operations and sulfuric acid plants. A sample of ground water collected from a 30-foot deep well in the area in 1944 contained 664 mg/l of chromium. Also, the concentration of copper sulfate in ground water was sufficiently high to warrant investigation of the economic feasibility of recovering and processing this compound.

This ground-water body contaminated with industrial waste, together with saline water that had encroached into the shallow aquifers underlying the industrial area, have led to corrosion of abandoned wells and intrusion of saline water into the deeper, fresh-water, artesian aquifer. The casings have developed holes or collapsed and act as conduits allowing the poor-quality water to migrate into the deeper artesian aquifer. At locations where leaky well casings are not in abundance, salt-water intrusion has not occurred because the artesian aquifer is protected by an overlying clay formation.

Other causes of casing failure have been related to stray electrical currents in the ground in the industrial area, which may cause holes to develop in well casings. Also, inadequate sealing of rotary-drilled water wells has allowed saline water to migrate downward along the annular space between the outer casing and the bore hole.

It is estimated that about 1,500 wells had been drilled in the industrial area up to 1950, of which more than 1,000 are no longer accessible. Many are covered by buildings, paved areas, and artificial fill. Only about 12 percent of the more than 1,000 abandoned wells have been plugged. A major portion of the remaining wells are probably the principal contributing factor to saline-water intrusion that has affected most of the industrial well fields in the area.

Discussions with drilling contractors in the region have revealed a number of other practices related to abandoned water wells that could lead to ground-water contamination. The most common observation was the destruction of water wells during demolition of buildings or houses in order to make way for new highways, to clear the way for road widening, or to prepare a site for construction of apartments, offices, and shopping centers. In most cases, the old wells serving the demolished houses are simply bulldozed over. The surface casings and seals are broken, and because of this, the old wells become a direct route for pollutants, such as highway deicing salts or sewage from leaky pipelines, to enter the underlying aquifer.

Operating wells can also act as conduits for pollutants to migrate into an aquifer. Normally this occurs because the annular space between the casing and the borehole is improperly sealed. Surveys of sanitary conditions of domestic wells in the region, some of which are summarized on page 152 of this report, indicate that a high percentage of privately-owned water wells in any particular area do not meet minimum health standards. Inspections by health authorities reveal that in numerous cases the well is not properly protected against contamination from overland runoff containing septic fluids, barnyard wastes, or storm waters and/or the water yielded by a particular well shows a relatively high concentration of bacteria. It was the general consensus of opinion of those health authorities interviewed that a high percentage of wells serving individual residences are sources of contamination in the immediate vicinity of the well but that public-supply wells serving communities are rarely operating under unsanitary conditions.

A number of states and local health agencies have adopted regulations and codes governing well construction and the plugging of abandoned wells. Also, water-well drillers must be licensed in eight out of the 11 states. New York is included as one of the eight states but licensing only applies to Long Island.

The regulations covering construction of public water-supply wells normally call for protection against flooding of the site, minimum distance from a potential source of pollution such as a sewer line, and minimum length of casing and surface grouting. However, the specific standards set by individual states vary considerably. For example, in Connecticut a protective radius of 200 feet is required between a public supply well and potential sources of contamination. In the neighboring state of Massachusetts the radius is 400 feet. In New Jersey, installation of a cement grout extending from land surface to a depth of 50 feet is rigidly enforced, whereas in many of the other states, codes covering this aspect of well construction are not specifically spelled out.

Only in Delaware, Maryland, New Jersey, Pennsylvania, and Long Island, New York is the plugging of abandoned wells mandatory.[34] Some of these states, for example in New Jersey, have issued explicit requirements that must be followed, such as material to be used. Enforcement of plugging of large diameter wells has been relatively successful because these are the same states where diversion rights for ground-water pumpage must be sought by application to the state. Thus, the existence and location of high capacity wells is generally recorded. Periodic reporting by ground-water users indicates when wells with diversion rights go out of service or are replaced. Thus, the state agency can follow up with a request for plugging the abandoned well. In the remaining states in the region, locations of operating public-supply and industrial wells are generally not recorded and enforcement of the plugging of abandoned wells would be extremely difficult. The same holds true for domestic and small commercial wells throughout the region.

Certainly more control is needed over the construction of domestic wells and the fate of abandoned wells. Also, licensing of well drillers in those states where such regulation does not exist would aid in correcting some of the faulty construction practices now in use in such areas. Most important of all, the arbitrary reasoning behind some of the rules involving such protective codes as distances to potential sources of contamination should be reevaluated. The origin of some of these codes dates back many decades, before the occurrence and movement of ground water under various hydrologic and geologic conditions was adequately understood.

AGRICULTURAL ACTIVITIES

A number of activities associated with crop growing, horticulture, dairy farming, and cattle raising can lead to contamination of ground-water supplies. Pollutants derived from fertilizers, pesticides, herbicides, animal wastes, and irrigation return flows can infiltrate with rain water or snow melt and eventually can be carried down to the underlying aquifer. Considerable treatment of waste products from agricultural activities takes place in the soil zone, and contamination of ground water from this source probably ranks very low in importance compared with other sources discussed in this report. The only exception to this is the application of fertilizers, which have affected ground-water quality in heavily cultivated areas such as the lower Connecticut River valley, where tobacco is a very important crop, and Long Island, New York, where potato farming is a major industry. In both of these regions, urbanization has changed land-use patterns and agricultural activity has declined radically since the early 1950's. However, nitrates related to heavy use of fertilizers during decades of cultivation are still contained in fresh-water aquifers and considerable time will be required before this pollutant has been flushed out. Undoubtedly, in other farm areas in the region, such as southern New Jersey, parts of Delaware and Maryland, and northern New England, contamination of aquifers over broad areas is occurring. However, population density is still low enough so that the problem remains relatively obscure.

One problem related to fertilizers and also herbicides that should not be overlooked is the potential for significant ground-water contamination from the large quantities of these two substances which are applied to lawns in suburban areas. It is conceivable that some of the high nitrate concentrations observed in ground waters underlying suburban areas may be caused by the heavy application of lawn fertilizers rather than agricultural activity which took place before the area became urbanized. Additional research on this subject is needed. In addition, more data is needed on whether the organic and inorganic compounds found in the various types of herbicides have penetrated the soil zone and entered the ground-water system in suburban areas.

A few cases of contamination of ground water from the application of pesticides have been noted in the region. Because of the lack of well-water analyses that include tests for pesticide compounds, it is difficult to tell whether the cases given below are unique or whether they represent a widespread problem.

*Water from a domestic well in Connecticut was affected by thallium which had been used in a rose spray. Apparently, thallium-rich waste water from the rose growing operation had seeped into the sandstone aquifer tapped by the domestic well. 189)

*Chlorinated hydrocarbons from pesticide spray used on cranberry bogs in Massachusetts have affected the water quality from at least one sand and gravel aquifer used for public supply. In another case in Massachusetts, the presence of chlorinated hydrocarbons from the operation of a greenhouse has been confirmed in a sample of water from a shallow sand and gravel aquifer. 190)

*A spring in New Hampshire has been found to contain traces of arsenic, presumably from the residue of pesticide sprays used for orchards. 191)

*Arsenate compounds used for insect control in the blueberry barrens of Maine have been found in surface streams and may have entered shallow ground-water aquifers. 192)

*Water from a domestic well in Pennsylvania was contaminated by chlordane applied to trenches around the house served by the well. The chlordane was used for termite control. 142)

With regard to barnyard or animal waste problems, discussions with health authorities indicate that many domestic wells in farm areas are contaminated because of the improper handling of manure combined with poor well construction. Normally the only well affected by a particular source of animal wastes is the well serving the same farm.

Irrigation is not widely practiced in the region and estimates of the proportion of irrigated land to total crop land are less than two percent. Based on this fact, it is doubtful that salinity problems related to irrigation return flows are significant in the study region. 193)

Agricultural activities in the traditional sense will probably decline in the future as the region becomes even more urbanized. However, the use of fertilizers, herbicides, and pesticides by individual home owners in suburban areas will continue, and the potential for contamination of ground water from these activities has not received enough attention in the past. There is a definite need for controlled studies of long-term affects from the application of commercial products sold for suburban agricultural use on lawns, gardens, trees, and shrubs. If it is found that ground-water quality is being affected, then consideration should be given to controls over the use of such products, and programs directed toward education of the public should be developed so that more efficient handling and application can be achieved.

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The use and purpose of monitoring wells should be better understood in the region. The general philosophy that monitoring wells are protective devices should be discouraged. Monitoring should be applied when there is a need to determine the status of ground-water quality at a particular location and to gain a perspective on long-term water quality at selected sites. At new sites, where a specific activity may lead to contamination of ground water, monitoring wells should be used only to determine whether procedures designed to protect ground-water quality have been successful. The monitoring wells themselves should not be considered as a method of preserving ground-water quality.

Existing Problems

The present approach toward existing problems in most states of the study region is to attempt corrective action only after a specific incident of ground-water contamination has been discovered. This "brush-fire" approach is not suitable in a region where use of ground water is increasing in importance. Furthermore, only a very small percentage of the existing problems have been discovered to date. Taking into account the tens of thousands of ground-water sources presently in use, there is the potential threat to the health of individuals in addition to the threat of adverse effects on industrial and agricultural activities.

Probably the most revealing aspect of this entire investigation is that significant numbers of cases of ground-water contamination do exist and have been documented for each of the sources discussed in SECTION VI. The importance of this rather elementary finding is that many of the activities causing known ground-water contamination cases are common throughout the region. Therefore, locating and evaluating additional cases should be of major concern to public agencies charged with the responsibility of protecting water quality. For example, for every landfill where pollutants have been discovered leaching into the underlying aquifer, there are hundreds more located in similar geologic settings and designed in the same manner, but for which no ground-water quality data are available. For every surface impoundment where it has been shown that pollutants are being added to the ground-water system, there are hundreds more being operated, unmonitored, under similar conditions.

It is recommended that a major effort be directed, within the financial resources available to local, state and federal agencies, toward defining the areal extent and severity of existing ground-water contamination problems. Research is needed to find the most suitable methods for such inventories. One possible method is the use of aerial photographic techniques, including remote sensing and multispectral photography, to locate potential sources of contamination such as salt piles and industrial waste lagoons. Another is the compilation of data already available on the locations of potential sources of contamination, such as areas containing high densities of septic tanks and routes of buried pipelines subject to leakage of toxic compounds. Much of this information has already been collected for other purposes. A third method is evaluation of chemical analyses of ground water already on file with public agencies. The success of this alternative would depend to a great degree on the availability of more complete analyses of water samples now collected from supply wells by public agencies in the region.

Essential to such inventories are methods that can be used to delineate the actual size and shape of contaminated ground-water bodies and the characteristics of the pollutants contained in an aquifer. The drilling of test holes is a standard technique used for gathering data on the areal extent of contaminated water zones and for collecting water samples. Wells will always be essential to such investigations, but drilling methods, details of design, and the materials selected must be applicable to the particular type of problem involved. A more scientific approach to present practices of drilling and constructing wells used for data collection and monitoring in cases of ground-water contamination is needed. Further research into the application of geophysical techniques is also warranted. For example, electrical resistivity has shown great promise for defining the presence of highly saline water bodies under certain geologic and hydrologic conditions, as has the use of differences in ground-water temperature for mapping the affected portion of an aquifer.

After inventories of ground-water contamination problems are underway, the results can begin to be used to warn against use of certain aquifers or portions of aquifers for specific purposes. Within the legal framework under which each state must operate, development or withdrawal of ground water could be limited in affected aquifer zones. It would be the task of the proper public agency to determine "critical zones" around each known significant case of ground-water contamination. In each "critical zone", ground-water diversion would be restricted from the standpoint of either the quantity that can be pumped or the purpose for which it can be used. Wells and other monitoring techniques would aid in determing when and how to modify the areal extent of a

Table 45. RESTRICTIONS ON GROUND-WATER USE IN THE CRITICAL ZONES SHOWN ON FIGURE 41.

Zone	Description	Restrictions on use of water-table aquifer	Restrictions on use of shallowest artesian aquifer
A	Area in which water-table aquifer already contains pollutant or ground-water quality is threatened because of proximity to contaminated area.	1. No ground-water pumpage permitted except where poor quality water can be used safely for special purposes or the pollutant can be successfully removed by treatment. 2. Ground-water quality monitored.	1. Pumpage regulated so that head is maintained above water table; otherwise pumpage not permitted. 2. Well construction strictly regulated to guard against inter-aquifer exchange of contaminated water. 3. Well-water quality periodically monitored.
B	Area in which natural process such as adsorption, dispersion, and ion exchange will have reduced the concentration of the pollutant significantly but not to a level acceptable for potable water supplies.	1. Ground-water pumpage limited to prevent significant increase in rate of travel of contaminated water. 2. Ground-water use for potable water supplies not permitted unless pollutant can be successfully removed by treatment. 3. Ground-water quality strictly monitored.	1. Pumpage regulated so that head is maintained above the water table in Zone A but can be lower than water table within this zone. 2. Well construction regulated.
C	Area in which natural processes will have reduced the concentration of the pollutant to a level acceptable for potable water supplies.	1. Ground-water pumpage limited to prevent significant increase in rate of travel of contaminated water. 2. Ground-water quality monitored.	Proposed ground-water users warned that pumpage may be restricted in the future if ground-water contamination spreads to Zone B.

dealing with such categories as extensive municipal landfills or application of highway deicing salts. Specific needs for research, regulation and monitoring of these and other sources are discussed later in this section.

Meanwhile, basic research is needed on how to cope with those cases in which pollutants in the ground-water system must be removed. This condition could present itself if no other alternative is reasonably available for replacement of threatened well supplies, or if pollutants being discharged from a ground-water source are contaminating a stream essential for water supply and recreational use. The present policy of most states in the region is to require that a pollutant be removed from an aquifer and that water quality be restored to its baseline conditions. However, such a policy breaks down because present methods available for removal and even containment of a pollutant are technically too difficult to apply and too costly to implement effectively.

Prevention of Additional Problems

Equally as pressing as the need to develop methods and strategies for dealing with existing problems of ground-water contamination is the need to establish ways to prevent future problems. Each of the 11 states in the study region already appears to have legislation which, although general in nature, would allow regulations and policies to be formulated and enforced for the prevention of ground-water quality degradation. Also, as pointed out in the previous section of this report, many codes in various states have been adopted to cover specific activities that can lead to ground-water contamination, such as those dealing with landfill siting, well construction, and sealing of surface impoundments. In addition, such broad approaches as New York State's classification of ground waters have been attempted as a means for preventing "pollution of ground waters". [1)]

Nevertheless, there has not been an overall evaluation of the various options available to regulatory agencies for protecting ground-water quality. Such alternatives for control as the setting of ground-water standards, enforcement of land-use restrictions in critical areas, imposition of restraints on each individual type of activity that can lead to ground-water contamination, and regulation of patterns of ground-water use should be explored. Obviously, the choice of any control method must be influenced by geologic and hydrologic conditions in the area of interest and must take into consideration the type of activity involved. Furthermore, any regulation, code, or policy must be tested against the following considerations:

3. Greater enforcement of proper construction and installation practices.

4. Enforcement of bans on discharge of hazardous wastes to septic-tank systems at industrial sites.

Buried Pipelines and Storage Tanks

1. Codes and regulations calling for consideration of factors involving design and management of proposed major pipelines carrying organic and inorganic pollutants as related to possible effects of leaks on underlying aquifers.

2. Consideration, in special cases of high risk to potable water supplies, of the use of liners in excavations containing buried pipelines and storage tanks.

3. More efficient monitoring of potential fluid losses, and regulations calling for the reporting of tank and pipeline failures.

4. Additional research into methods for removing hydrocarbons from unconsolidated and rock aquifers.

5. Additional research into the overall effects of leaky sanitary and storm sewers on ground-water quality.

Application and Storage of Highway Deicing Salts

1. Greater effort to reduce wastage of salt by means of equipment modification and education of those involved in salt spreading.

2. Additional research to better determine the role that highway deicing salts play in the degradation of water quality in the various aquifers of the region.

3. Consideration of aquifer susceptibility to contamination in the design of highway drainage systems.

4. Guidelines governing the siting, construction, and overall protection of water wells located in close proximity to existing and proposed major highways.

5. Research into the significance of naturally occurring and artificially added trace elements in highway deicing salts.

6. Protection of ground water from salt-storage areas.

Landfills

1. Inventories of industrial and municipal landfills.

2. Increased monitoring of ground-water quality in the vicinity of landfills.

3. Additional research on: the character of leachate from landfills; the ability of underlying natural soils to reduce the concentrations of different types of leachate; the effects of various types of cover material, slopes, and other landfill operational procedures on rainfall infiltration rates.

4. Additional research into the use and composition of clay and synthetic liners, methods of leachate collection, and processes for the treatment of leachate.

5. Development of procedures for completing landfills to minimize the continued production of leachate after waste disposal operations have ended.

6. Enforcement of regulations prohibiting disposal of toxic wastes in landfills.

7. Review of existing guidelines governing the siting and design of new landfills.

Surface Impoundments

1. Development of guidelines and procedures for the siting and design of proposed surface impoundments.

2. Research into the need for and design of artificial liners for surface impoundments containing various types of organic and inorganic pollutants.

3. Inventories of existing surface impoundments, chemicals and wastes being stored, and design and operation of these systems.

4. Increased monitoring of ground-water quality in the vicinity of surface impoundments and monitoring of losses of liquids to the ground-water system from surface impoundments.

5. Evaluation of the use of surface impoundments as a means of treatment of municipal and industrial wastes in the northeast versus their potential for causing ground-water quality degradation.

used or proposed.

7. Evaluation of guidelines presently being used to control site selection and the type of waste tolerated where municipal and industrial effluent is applied to the land.

Water Wells

1. More uniform and effective controls over well construction practices and the siting of wells.

2. More effective control over the fate of abandoned wells.

Agricultural Activities

1. Research into the effects on ground-water quality of the application of fertilizers, herbicides, and insecticides in urban areas.

2. Greater control over agricultural practices that lead to contamination of shallow aquifers tapped by domestic wells in rural areas.

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SECTION IX

APPENDIX A - GLOSSARY OF TERMS

Alluvium - Clay, silt, sand, gravel, or other rock materials transported by flowing water and deposited in comparatively recent geologic time as sorted or semi-sorted sediments in riverbeds, estuaries, flood plains, lakes, shores and in fans at the base of mountain slopes.

Aquiclude (Confining Bed) - A body of less permeable material than the adjacent aquifer(s).

Aquifer - A geologic formation, group of formations, or part of a formation that is water yielding.

Artesian - The occurrence of ground water under sufficient pressure to rise above the upper surface of the aquifer.

Artesian Aquifer - An aquifer overlain by a confining bed and containing water under artesian conditions.

Artificial Recharge - The addition of water to the ground-water reservoir by activities of man, such as irrigation, or spreading basins.

Base Flow - The fair-weather flow of streams, composed largely of ground-water effluent.

Biochemical Oxygen Demand (BOD) - The quantity of oxygen utilized primarily in the biochemical oxidation of organic matter in a specified time and at a specified temperature. The time and temperature are usually five days and 20°C.

Brackish Water - Water containing dissolved minerals in excess of acceptable potable water standards, but less than that of sea water.

Chemical Oxygen Demand (COD) - The measure of the readily oxidizable material in water which provides an approximation of the minimum amount of organic and reducing material present.

Chemical Water Quality - The nature of water as determined by the concentration of chemical constituents.

Clastic - Consisting of fragments of rocks or organic structures that have been moved individually from their places of origin.

Concentration - The weight of solute dissolved in a unit volume of solution.

Connate Water - Water that was deposited simultaneously with the sediments, and has not since then existed as surface water or as atmospheric moisture.

Consumptive Use - The quantity of water discharged to the atmosphere or incorporated in the products of vegetative growth or industrial processes.

Contamination - The degradation of natural water quality as a result of man's activities, to the extent that its usefulness is impaired.

Crystalline - Rock composed of crystals or fragments of crystals.

Degradable - Capable of being decomposed, deteriorated, or decayed into simpler forms with characteristics different from the original. Also referred to as biodegradable.

Degradation of Water Quality - The act or process of reducing the level of water quality so as to impair its original usefulness.

Demineralization - The process of reducing the concentration of chemical constituents.

Domestic Well - A well which supplies water for the occupants of a single residence.

Drawdown - The lowering of the water table or peizometric surface caused by pumping or artesian flow.

Evapotranspiration - The combined processes of evaporation from land, water, and other surfaces, and transpiration by plants.

Fall Line - A line joining the waterfalls on a number of successive rivers that marks the point where each river descends from the upland (Piedmont) to the lowland (Coastal Plain).

Flood Plain - The flat ground along a stream course which is covered by water at flood stage.

Fluvial Sediment - Those deposits produced by stream or river action (see Alluvium).

Glacial Drift - Boulders, till, gravel, sand or clay transported by a glacier or its meltwater.

Porosity - The relative volume of the pore spaces between mineral grains in a rock as compared to the total rock volume.

Primary Treatment (Sewage) - The removal of larger solids by screening, and of more finely divided solids by sedimentation.

Production Well - A well from which ground water is obtained.

Public Supply Well - A well from which ground water is obtained serving more than one individual or household.

Recharge Basin - A basin designed for the purpose of adding water to the ground-water reservoir.

Salt-Water Intrusion (or Encroachment) - Movement of salty ground water so that it replaces fresh ground water.

Saturation, Zone of - The zone in which interconnected interstices are saturated with water under pressure equal to or greater than atmosphere.

Secondary Treatment - The oxidation of organic matter in sewage through bacterial action.

Sedimentary Rock - Rocks formed by the accumulation of sediment.

Soft Water - Water containing 60 mg/l or less of hardness.

Specific Capacity - The rate of discharge of water from a well divided by the drawdown of the water level in it. Properly stated, it relates to the time of pumping.

Storage (Aquifer) - The volume of water held in the interstices of the rock.

Surface Water - That portion of water that appears on the land surface.

Tertiary Treatment - Advanced waste treatment which removes additional impurities which remain in the effluent after secondary treatment.

Transmissivity - The rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient.

Unconsolidated Rocks - Uncemented or loosely coherent rocks.

Water Cycle - The complete cycle through which water passes; water vapor in the atmosphere, liquid and solid as precipitation as part of surface and ground water and eventually back to atmospheric vapor.

Water Quality - Pertaining to the chemical, physical and biological constituents found in water and its suitability for a particular purpose.

Water Table - That surface in an unconfined water body at which the pressure is atmospheric. It is defined by the levels at which water stands in wells that penetrate the water body just far enough to hold standing water.

Water-Table Aquifer - An aquifer containing water under water-table conditions.

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GROUND WATER CONTAMINATION IN THE NORTHEAST STATES

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68-01-0777

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An evaluation of principal sources of ground-water contamination has been carried out in 11 northeast states, including all of New England, New York, New Jersey, Pennsylvania, Maryland, and Delaware. The findings of this study have been used to determine priorities for research into ways to correct existing sources of contamination and to point out deficiencies in present control methods for protection against further degradation of ground-water quality. Principal sources of ground-water quality degradation caused by man's activities that are common to most parts of the region are septic tanks and cesspools, buried tanks and pipelines including sanitary and storm sewers, the application and storage of highway deicing salts, municipal and industrial landfills of solid waste, unlined surface impoundments, spills, and the uncontrolled discharge of pollutants on the land surface. In New York and Pennsylvania, mining and petroleum exploration and development have caused many instances of ground-water contamination, but the extent of the problem has not been defined. Salt-water intrusion in coastal areas has been adequately controlled, but little is known of the potential threat to fresh-water aquifers from the encroachment of saline water that naturally occurs in inland formations underlying the western portions of the region.

*Ground water, *water pollution, *landfills, *septic tanks, *waste storage

Northeast United States, Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Vermont.

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